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TECHNICAL PAPERS

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FOREWORD

The *Proceedings* of the American Society for Testing Materials are published annually and include all reports and papers offered to the Society during the current year and accepted by the Administrative Committee on Papers and Publications for the *Proceedings*, together with discussion.

The table of contents and subject and author indexes cover all papers and reports published by the Society during the current year, which in addition to those appearing in the *Proceedings* include those accepted for publication in the ASTM BULLETIN or in Special Technical Publications.

A list of the Special Technical Publications published by the Society in 1955 is given on page 1250 of this volume. This supplements the lists appearing in the *Proceedings* from 1948 to 1954 covering all special publications published by the Society up to and including 1954.

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and opinions advanced in this publication

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A Laboratory Grinding Machine for Preparing Test Specimens from Rubber and Other Flexible Products—S. A. Eller and W. K. Gondek (*see* ASTM Bulletin *No. 206, May, 1955, p. 70* (*TP 118*))

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SUMMARY OF PROCEEDINGS

OF THE

FIFTY-EIGHTH ANNUAL MEETING

Atlantic City, N. J., June 27–July 1, 1955

This summary of the Fifty-eighth Annual Meeting of the American Society for Testing Materials, held at the Chalfonte-Haddon Hall Hotel, Atlantic City, N. J., June 27–July 1, 1955, is a record of the transactions of the meeting, including the actions taken on the various recommendations submitted by the technical committees. In all, 32 technical sessions were held.

The registered attendance of the meeting is as follows: Members present or represented, 1341; committee members, 862; guests, 323; total, 2537; ladies, 234.

The Proceedings are set forth session by session. There were 66 reports and 93 formal papers presented. The record with respect to each has been briefed, the recommendations in the reports have been grouped so as to cover the acceptance of material for publication as tentative, such as new specifications, methods of test, revisions of tentatives, and proposed revisions of existing standards, and, as a separate group, the approval of matters that were referred to letter ballot of the Society, comprising the adoption of tentatives as standard and the adoption of revisions of standards. Accordingly, wherever the action is reported "adopted as standard" or "adopted as standard, revisions in," it is understood that this indicates approval of the Annual Meeting for reference to letter ballot of the Society.[1] The various recommendations so recorded are included in the Society letter ballot. The actions designated as "accepted as tentative" or "accepted as tentative, revisions in" are self-evident as indicating acceptance by the Society at the Annual Meeting for publication as tentative. Designations that have since been assigned to new tentatives are included as information.

All papers, unless otherwise noted, appear in this publication.

While all the items on the program are recorded under the particular session in which they are presented, for convenience in locating actions with respect to any particular report, the accompanying list is presented of all reports together with the page reference where the actions thereon are recorded:

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[1] The letter ballot on recommendations affecting standards and on Amendments to By-laws, distributed to the Society membership, will be canvassed on September 12, 1955; see Editor's Note, p. 38.

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FIRST SESSION—OPENING SESSION

MONDAY, JUNE 27, 10:00 A.M.

FORMAL OPENING OF THE FIFTY-EIGHTH ANNUAL MEETING, PRESIDENT N. L. MOCHEL

The session was first formally opened by President N. L. Mochel, who called attention to the very complete program of events that were to follow during the ensuing week. The meeting was then turned over to the session chairman, W. W. Werring, Bell Telephone Laboratories, Inc.

SYMPOSIUM ON IMPACT TESTING[2]

SESSION CHAIRMAN: W. W. WERRING

SESSION SECRETARY: W. H. MAYO

Notched-Bar Testing—Theory and Practice—S. L. Hoyt, presented by the author.

Transition Behavior in V-Notch Charpy Slow Bend and Impact Tests—Carl E. Hartbower, presented by the author.

Reproducibility of Charpy Impact Testing—David E. Driscoll, presented by the author.

Automatic Impact Testing to −236 C—Thomas S. DeSisto, presented by the author.

(*Symposium Continued in Second Session*)

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[2] Issued as separate publication *ASTM STP No. 176*.

SECOND SESSION—SYMPOSIUM ON IMPACT TESTING[2]

(Symposium Continued from First Session)

MONDAY, JUNE 27, 2:00 P.M.

SESSION CHAIRMAN: F. G. TATNALL

SESSION SECRETARY: H. L. FRY

The Influence of Pendulum Flexibilities on Impact Energy Measurements—J. I. Bluhm, presented by the author.

The Impact Tube: A New Experimental Technique for Applying Impulse Loads—George Gerard, presented by the author.

Longitudinal Impact Tests of Long Bars with a Slingshot Machine—W. Ramberg and L. K. Irwin, presented by Mr. Ramberg.

Shock Tester for Shipping Containers—W. H. Cross and Max McWhirter, presented by Mr. Cross.

Properties of Concrete at High Rates of Loading—D. Watstein, presented by the author.

THIRD SESSION—SOILS

MONDAY, JUNE 27, 2:00 P.M.

SESSION CHAIRMAN: K. B. WOODS

Soil Density Determination by Direct Transmission of Gamma Rays—R. K. Bernhard and M. Chasek, presented by Mr. Bernhard.

Pressure Distribution Along Friction Piles—L. C. Reese and H. B. Seed, presented by Mr. Seed.

Relationship Between Soil Moisture Tension Values and the Consistency Limits of Soils—Ralph L. Rollins and D. T. Davidson, presented by Mr. Rollins (not published).

The Use of Laboratory Tests to Develop Design Criteria for Protective Filters—K. P. Karpoff, presented by W. G. Holtz.

Some Laboratory Tests for the Evaluation of Stabilized Soils—T. Y. Chu and D. T. Davidson, presented by title only (not published).

FOURTH SESSION—TESTING

MONDAY, JUNE 27, 8:00 P.M.

SESSION CHAIRMAN: E. K. SPRING

A Remotely Operated Extensometer—R. G. Berggren and J. C. Wilson, presented by Mr. Berggren.[3]

Certain Departures from Plastic Ideality at Large Strains—H. A. Lequear and J. D. Lubahn, presented by Mr. Lubahn.

A Diameter Gage and Dynamometer for True Stress-Strain Tension Tests—G. W. Powell, E. R. Marshall, and W. A. Backofen, presented by title only.

High-Speed Tension Testing Machine for Plastics—James Dorsey, Frederick J. McGarry, and Albert G. H. Dietz, presented by Mr. Dorsey.[4]

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[3] Published in the ASTM BULLETIN, No. 210, December, 1955, p. 35 (TP211).

[4] Published in the ASTM BULLETIN, No. 211, January, 1956, p. 34 (TP6).

FIFTH SESSION—DISCUSSION ON JUDGMENT FACTORS IN SOILS TESTING[5]

TUESDAY, JUNE 28, 9:30 A.M.

SESSION CHAIRMAN: R. F. LEGGET

Introduction—R. F. Legget.

The History and Development of Committee D-18—E. J. Kilcawley, presented by the author.

Judgment Factors and the Environment in Soil Testing—D. M. Burmister, presented by the author.

Critical Review Work of Committee D-18—A. E. Cummings, presented by the author.

Future Possibilities and Activities of Committee D-18—K. B. Woods, presented by the author.

C. A. Hogentogler Award:

The second presentation of this award, established by Committee D-18 in honor of its First Chairman and given in recognition of a paper of outstanding merit on soils for engineering purposes presented before the Society, was made to H. G. Mason and J. A. Bishop, U. S. Naval Civil Engineering Research and Evaluation Laboratory, Port Hueneme, Calif., and to L. A. Palmer and P. P. Brown, Bureau of Yards and Docks, Washington, D. C., for their two-part paper on "Piles Subjected to Lateral Thrust," presented at the 1954 Annual Meeting and published in the Supplement to the Symposium on Lateral Load Tests on Piles, STP No. 154-A.

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[5] This discussion was intended as a critical review of the activities of Committee D-18. It was not made a matter of record for publication.

SIXTH SESSION—NON-FERROUS METALS

TUESDAY, JUNE 28, 9:30 A.M.

SESSION CHAIRMAN: G. H. HARNDEN

Mechanical Properties of a Magnesium Alloy Under Biaxial Tension at Low Temperatures—Edward Paxson, Joseph Marin, and L. W. Hu, presented by Mr. Paxson.

Strength of Bent Copper Tube—G. S. Sangdahl, Jr., and W. M. Baldwin, Jr., presented by Mr. Baldwin.

Effect of Specimen Dimensions on High-Temperature Mechanical Properties—Paul Shahinian and Joseph R. Lane, presented by Mr. Shahinian.

Committee B-1 on Wires for Electrical Conductors:

Report presented in the absence of the chairman by B. J. Sirois, and the following actions taken:

Accepted as Tentative:

Spec. for Silver-Coated Soft or Annealed Copper Wire (B 298 - 55 T)

Accepted as Tentative, Revisions in:

Spec. for Hard-Drawn Aluminum Wire for Electrical Purposes (B 230 - 54 T)

Spec. for Concentric-Lay-Stranded Aluminum Conductors, Steel-Reinforced (ACSR) (B 232 - 53 T)

Adopted as Standard:

Spec. for Rope-Lay-Stranded Copper Conductors Having Bunch-Stranded Members for Electrical Conductors (B 172 - 53 T)

Spec. for Rope-Lay-Stranded Copper Conductors Having Concentric-Stranded Members for Electrical Conductors (B 173 - 53 T)

Spec. for Bunch-Stranded Copper Conductors for Electrical Conductors (B 174 - 53 T)
Spec. for Standard Weight Zinc-Coated (Galvanized) Steel Core Wire for Aluminum Conductors, Steel Reinforced (ACSR) (B 245 - 52 T)
Spec. for Zinc-Coated (Galvanized) Steel Core Wire (with Coatings Heavier than Standard Weight) for Aluminum Conductors, Steel Reinforced (ACSR) (B 261 - 52 T)
Spec. for Three-Quarter Hard Aluminum Wire for Electrical Purposes (B 262 - 52 T)

Adopted as Standard, Revisions in:

Spec. for Bronze Trolley Wire (B 9 - 53)
Spec. for Copper Trolley Wire (B 47 - 52)
Spec. for Soft Rectangular and Square Bare Copper Wire for Electrical Conductors (B 48 - 52)
Spec. for Hard-Drawn Copper Alloy Wires for Electrical Conductors (B 105 - 53)
Spec. for Figure-9 Deep-Section Grooved and Figure-8 Copper Trolley Wire for Industrial Haulage (B 116 - 52)
Spec. for Concentric-Lay-Stranded Aluminum Conductors, Hard-Drawn and Three-Quarter Hard-Drawn (B 231 - 54), with the withdrawal from the report as preprinted of the revision of Section 5(*e*).
Spec. for Rolled Aluminum Rods (EC Grade) for Electrical Purposes (B 233 - 54)

Reapproval of Standard:

Test for Resistivity of Electrical Conductor Materials (B 193 - 49)

The committee withdrew from the report as preprinted the recommendation for revision, immediate adoption, of the Standard Spec. for Concentric-Lay-Stranded Copper Conductors, Hard, Medium-Hard, or Soft (B 8 - 53).

Committee B-5 on Copper and Copper Alloys, Cast and Wrought:

Report presented by V. P. Weaver, secretary, and the following actions taken:

Accepted as Tentative:

Spec. for Tellurium Copper Rod (B 301 - 55 T)
Spec. for Threadless Copper Pipe (B 302 - 55 T)

Accepted as Tentative, Revisions in:

Spec. for Copper-Nickel-Zinc Alloy (Nickel Silver) and Copper-Nickel Alloy Plate, Sheet, Strip, and Rolled Bar (B 122 - 54 T)
Spec. for General Requirements for Wrought Copper and Copper-Alloy Plate, Sheet, Strip, and Rolled Bar (B 248 - 53 T)
Spec. for General Requirements for Wrought Copper and Copper-Alloy Rod, Bar, and Shapes (B 249 - 53 T)
Spec. for General Requirements for Wrought Copper and Copper-Alloy Wire (B 250 - 52 T)
Spec. for General Requirements for Wrought Seamless Copper and Copper-Alloy Pipe and Tube (B 251 - 54 T)
Spec. for Seamless Copper Tube for Refrigeration Field Service (B 280 - 53 T)
Spec. for Copper-Zinc-Manganese Alloy (Manganese Brass) Sheet and Strip (B 291 - 54 T)

Adopted as Standard, Revisions in:

Spec. for Copper Plates for Locomotive Fire Boxes (B 11 - 54)
Spec. for Copper Rods for Locomotive Staybolts (B 12 - 54)
Spec. for Seamless Copper Boiler Tubes (B 13 - 49)
Spec. for Cartridge Brass Sheet, Strip, Plate, Bar, and Disks (B 19 - 54)
Spec. for Brass Plate, Sheet, Strip, and Rolled Bar (B 36 - 52)
Spec. for Seamless Copper Pipe, Standard Sizes (B 42 - 54)
Spec. for Seamless Red Brass Pipe, Standard Sizes (B 43 - 54)
Spec. for Seamless Copper Tube, Bright Annealed (B 68 - 54)
Spec. for Seamless Copper Tube (B 75 - 54)
Spec. for Seamless Copper Water Tube (B 88 - 54)
Spec. for Copper-Silicon Alloy Plate and Sheet for Pressure Vessels (B 96 - 54)
Spec. for Copper-Silicon Alloy Plate, Sheet, Strip, and Rolled Bar for General Purposes (B 97 - 54)
Spec. for Copper-Silicon Alloy Rod, Bar, and Shapes (B 98 - 54)
Spec. for Rolled Copper-Alloy Bearing and Expansion Plates and Sheets for Bridge and Other Structural Uses (B 100 - 54)
Spec. for Phosphor Bronze Plate, Sheet, Strip, and Rolled Bar (B 103 - 51)
Spec. for Copper and Copper-Alloy Seamless Condenser Tubes and Ferrule Stock (B 111 - 54)
Spec. for Leaded Brass Plate, Sheet, Strip, and Rolled Bar (B 121 - 52)
Spec. for Copper and Copper-Base Alloy Forging Rod, Bar, and Shapes (B 124 - 54)
Spec. for Cartridge Brass Cartridge Case Cups (B 129 - 51)
Spec. for Commercial Bronze Strip (B 130 - 54)

Spec. for Commercial Bronze Bullet Jacket Cups (B 131 – 54)
Spec. for Seamless Brass Tube (B 135 – 54)
Spec. for Copper-Nickel-Zinc Alloy (Nickel Silver) Rod and Bar (B 151 – 52)
Spec. for Copper Sheet, Strip, Plate, and Rolled Bar (B 152 – 54)
Test for Expansion (Pin Test) of Copper and Copper-Alloy Tubing (B 153 – 47)
Spec. for Aluminum Bronze Plate, Sheet, Strip, and Rolled Bar (B 169 – 52)
Spec. for Copper-Alloy Condenser Tube Plates (B 171 – 54)
Spec. for Copper Bus Bar, Rod, and Shapes (B 187 – 54)
Spec. for Seamless Copper Bus Pipe and Tube (B 188 – 54)
Spec. for Copper-Beryllium Alloy Plate, Sheet, Strip, and Rolled Bar (B 194 – 52)

Withdrawal of Standard:

Spec. for Seamless Brass Boiler Tubes (B 14 – 54)

Paper Appended:

Mr. G. R. Gohn was then called upon to present his paper on "A Hardness Conversion Table for Copper-Beryllium Alloy Strip" appearing as an appendix to the report.

SEVENTH SESSION—LUNCHEON, PRESENTATION OF AWARDS OF MERIT, INTRODUCTION OF NEW OFFICERS, PRESIDENT'S ADDRESS, AWARD OF HONORARY MEMBERSHIPS, REPORT OF BOARD OF DIRECTORS, RECOGNITION OF 50- AND 40-YEAR MEMBERS

TUESDAY, JUNE 28, 12:00 NOON

SESSION CHAIRMAN: PAST-PRESIDENT L. C. BEARD, JR.

About 360 were present at this annual luncheon session, including a number of ladies and visitors.

Awards of Merit:

The Chairman of the 1955 Award of Merit Committee, C. R. Stock, read brief citations and presented the following to President Mochel, who conferred on them, on behalf of the Board of Directors, the certificate of the Award of Merit:

Boris J. Barmack
Edward J. Kilcawley
Christopher E. Loos
Robert J. McKay
William T. Pearce
Nathan C. Rockwood
Robert B. Sosman
George N. Thompson
William S. Young
William A. Zinzow

Election of Officers:

Results of the letter ballot on election of new officers were announced by F. G. Tatnall on behalf of the Tellers' Committee consisting of Percival Theel, chairman, and Mr. Tatnall. The results were as follows:

For President, to serve for one year:
  C. H. Fellows, 966 votes.
For Vice-President, to serve for two years:
  R. T. Kropf, 957 votes.
For Directors, to serve for three years:
  R. C. Alden, 952 votes.
  A. A. Bates, 952 votes.
  F. L. LaQue, 955 votes.
  E. F. Lundeen 949 votes.
  J. C. Moore, 948 votes.

The newly-elected members of the Board of Directors who were present were introduced, as were President-elect Fellows and Vice-President Kropf, the latter two men responding briefly.

Presidential Address:

The annual President's Address was presented by N. L. Mochel, his subject being "What Is It?" This address is printed in the July, 1955, ASTM BULLETIN.

Award of Honorary Memberships:

The Executive Secretary read citations for the following four members who had been elected by the Board of

Directors to Honorary Membership in the Society:

W. M. Barr
T. A. Boyd
Arthur W. Carpenter
R. L. Templin

Mr. Mochel presented the certificate to Messrs. Barr, Boyd, and Carpenter. Mr. Templin's son Gordon received the certificate for his father.

Report of the Board of Directors:

R. J. Painter, Executive Secretary, presented a brief résumé of the Report of the Board of Directors, and submitted for action an amendment to the By-laws covering the establishment of a new grade of Associate Member in lieu of the present grade of Junior Member. This affects Article I, Sections 1, 5, 6, and 8, and Article VIII, Sections 1 and 2.

The amendment was approved for reference to letter ballot.

Recognition of 50- and 40-Year Members, Special Presentations:

Chairman Beard read the names of eight members, both individual and company, who had been continuously affiliated with the Society for 50 years. Certificates to that effect were presented. The procedure was repeated for forty 40-year members. A complete list of the 50- and 40-year members appears in the July, 1955, ASTM BULLETIN.

The chairman then presented the Past-President's pin to retiring President N. L. Mochel. Mention was made that this meeting brings to a close for T. S. Fuller eight consecutive years on the Board of Directors, as Director, Vice-President, President, and Past-President. Recognition was also given to G. R. Gohn, W. H. Lutz, H. K. Nason, A. O. Schaefer, and M. A. Swayze as retiring directors.

EIGHTH SESSION—STEEL

TUESDAY, JUNE 28, 2:30 P.M.

SESSION CHAIRMAN: L. H. WINKLER

Effect of Strain-Rate History on the Creep Behavior of an Alloy Steel at 800 F—H. A. Lequear and J. D. Lubahn, presented by Mr. Lubahn.

Effects of Neutron Irradiation in Steels—J. C. Wilson and R. G. Berggren, presented by Mr. Wilson.

Effect of Time and Temperature on Impact and Tensile Properties of Hot-Rolled Low Carbon Steels During Strain Aging—F. Garofalo, G. V. Smith, and D. C. Marsden, presented by Mr. Garofalo.

An Investigation of the 21 Per Cent Chromium-10 Per Cent Nickel Heat-Resistant Alloy—R. J. Mangone, D. D. Burgan, and A. M. Hall, presented by Mr. Hall.

Electron Microstructure of Bainite and Tempered Martensite in Steel—D. M. Teague and S. T. Ross, presented by Mr. Teague.

TECHNICAL SESSION ON NON-DESTRUCTIVE TESTING

TUESDAY, JUNE 28, 2:30 AND 8:00 P.M.

Committee E-7 on Non-Destructive Testing sponsored a technical discussion session on Non-Destructive Testing which followed the main meeting of the committee. The afternoon session consisted of the following two papers:

Ionography—E. L. Crisculo.

The Quality of Radiographic Inspection—D. T. O'Connor.

Panel Discussion

After the presentation of the papers the meeting continued in the form of a panel discussion entitled:

"What ASTM Specifications and Related Activities Mean to Us."

NINTH SESSION—REPORT SESSION

TUESDAY, JUNE 28, 4:30 P.M.

SESSION CHAIRMAN: L. J. JACOBI

Committee A-2 on Wrought Iron:

Report presented by A. D. Morris, chairman, and the following actions taken:

Adopted as Standard:

Spec. for Wrought Iron Plates (A 42 - 52 T)
Spec. for Welded Wrought Iron Pipe (A 72 - 52 T)
Spec. for Staybolt Wrought Iron, Solid (A 84 - 52 T)
Spec. for Staybolt Wrought Iron, Hollow-Rolled (A 86 - 52 T)

Adopted as Standard, Revisions in:

Spec. for Wrought Iron Rolled or Forged Blooms and Forgings (A 73 - 39)

Withdrawal of Standard:

Spec. for Refined Iron Bars (A 41 - 36)

Committee A-6 on Magnetic Properties:

Report presented by A. C. Beiler, chairman, and the following actions taken:

Adopted as Standard, Revisions in:

Methods of Testing Magnetic Materials (A 34 - 53)
Test for Normal Induction and Hysteresis of Magnetic Materials (A 341 - 49)
Spec. for Flat-Rolled Electrical Steel (A 345 - 49)

Withdrawal of Tentatives:

Spec. for Flat-Rolled Grain Oriented Electrical Steel, 3 Per Cent Silicon Content, in Cut Lengths or Coils (A 378 - 54 T)
Spec. for Flat-Rolled Electrical Steel, 3.5 to 5 Per Cent Silicon Content, in Cut Lengths or Coils (A 379 - 54 T)
Spec. for Flat-Rolled Electrical Steel (A 345 - 54 T)

Reapproval of Standards:

Def. of Terms, with Symbols, Relating to Magnetic Testing (A 340 - 49)
Test for Permeability of Feebly Magnetic Materials (A 342 - 53)
Test for Alternating Current Core Loss and Permeability of Magnetic Materials (A 343 - 54)
Test for Electrical and Mechanical Properties of Magnetic Materials (A 344 - 52)

Committee B-2 on Non-Ferrous Metals and Alloys:

Report presented by Bruce W. Gonser, chairman, and the following actions taken:

Accepted as Tentative:

Spec. for Titanium Sponge (B 299 - 55 T). Extensive changes in the specifications as preprinted were presented by the committee and these changes are subject to letter ballot approval of Committee B-2.

Accepted as Tentative, Revisions in:

Spec. for Fire-Refined Casting Copper (B 72 - 47 T)

Adopted as Standard, Revisions in:

Spec. for Pig Lead (B 29 - 49)

Withdrawal of Tentatives:

Spec. for Titanium Ingot (B 264 - 52 T)
Spec. for Iodide Titanium (B 266 - 52 T)

Reapproval of Standards:

Spec. for Lake Copper Wire Bars, Cakes, Slabs, Billets, Ingots, and Ingot Bars (B 4 - 42)
Spec. for Electrolytic Copper Wire Bars, Cakes, Slabs, Billets, Ingots, and Ingot Bars (B 5-43)
Spec. for Slab Zinc (Spelter) (B 6 - 49)
Spec. for White Metal Bearing Alloys (Known Commercially as 'Babbit Metal') (B 23 - 49)
Spec. for Soft Solder Metal (B 32 - 49)
Spec. for Nickel (B 39 - 22)
Spec. for Rolled Zinc (B 69 - 39)
Spec. for Lead-Coated Copper Sheets (B 101 - 40)
Spec. for Electrolytic Cathode Copper (B 115 - 43)
Spec. for Oxygen-Free Electrolytic Copper Wire Bars, Billets, and Cakes (B 170 - 47)
Spec. for Fire-Refined Copper for Wrought Products and Alloys (B 216 - 49)
Spec. for Metallic Antimony (B 237 - 52)
Classification of Coppers (B 224 - 52)

Committee B-4 on Metallic Materials for Electrical Heating, Electrical Resistance, and Electronic Applications:

Report presented by E. I. Shobert, II, vice-chairman, and the following actions taken:

Accepted as Tentative:

Test for Interface Impedance Characteristics of Vacuum Tube Cathodes (B 300 - 55 T)

Adopted as Standard:

Test for Hardness of Electrical Contact Materials (B 277 - 52 T)

Committee B-8 on Electrodeposited Metallic Coatings:

Report presented by C. H. Sample, chairman, and the following actions taken:

Accepted as Tentative, Revisions in:

Spec. for Electrodeposited Coatings of Nickel and Chromium on Steel (A 166 - 54 T)
Spec. for Electrodeposited Coatings of Lead on Steel (B 200 - 54 T)
Spec. for Chromate Finishes on Electrodeposited Zinc, Hot-Dipped Galvanized, and Zinc Die-Case Surfaces (B 201 - 54 T)

Adopted as Standard, Revisions in:

Spec. for Electrodeposited Coatings of Zinc on Steel (A 164 - 53)
Spec. for Electrodeposited Coatings of Cadmium on Steel (A 165 - 53)
Spec. for Electrodeposited Coatings of Nickel and Chromium on Copper and Copper-Base Alloys (B 141 - 45)
Spec. for Electrodeposited Coatings of Nickel and Chromium on Zinc and Zinc-Base Alloys (B 142 - 54)
Rec. Practice for Chromium Plating on Steel for Engineering Use (B 177 - 49)

Reapproval of Standard:

Rec. Practice for Preparation of Low-Carbon Steel for Electroplating (B 183 - 49)

Committee B-9 on Metal Powders and Metal Powder Products:

Report presented in the absence of the chairman by F. V. Lenel, and the following actions taken:

Accepted as Tentative:

Spec. for Copper Infiltrated Iron Parts (B 303 - 55 T)

Accepted as Tentative, Revisions in:

Spec. for Metal Powder Sintered Bearings (B 202 - 51 T)

Adopted as Standard:

Def. of Terms Used in Powder Metallurgy (B 243 - 49 T)

Reapproval of Standards:

Test for Apparent Density of Metal Powders (B 212 - 48)
Test for Flow Rate of Metal Powders (B 213 - 48)
Test for Sieve Analysis of Granular Metal Powders (B 214 - 48)
Method of Sampling Finished Lots of Metal Powders (B 215 - 48)

Committee E-7 on Non-Destructive Testing:

Report presented by J. H. Bly, chairman, and the following action taken:

Accepted as Tentative:

Method for Dry Powder Magnetic Particle Inspection (E 109 - 55 T)

TENTH SESSION—REPORT SESSION

TUESDAY, JUNE 28, 4:30 P.M.

SESSION CHAIRMAN: DOUGLAS E. PARSONS

Committee C-20 on Acoustical Materials:

Report presented in the absence of the chairman by L. C. Gilbert, and the following action taken:

Accepted as Tentative:

Test for Strength Properties of Prefabricated Architectural Acoustical Materials (C 367 - 55 T)

Committee D-16 on Industrial Aromatic Hydrocarbons and Related Materials:

Report presented by D. F. Gould, chairman, and the following actions taken:

Adopted as Standard, Revisions in:

Test for Distillation of Industrial Aromatic Hydrocarbons (D 850 - 50)

Reapproval of Standards:

Test for Acidity of Benzene, Toluene, Xylenes, and Similar Industrial Aromatic Hydrocarbons (D 847 - 47)
Test for Acid Wash Color of Benzene, Toluene, Xylenes, Refined Solvent Naphthas, and Similar Industrial Aromatic Hydrocarbons (D 848 - 47)
Test for Copper Corrosion of Industrial Aromatic Hydrocarbons (D 849 - 47)
Test for Paraffins in Industrial Aromatic Hydrocarbons (D 851 - 47)
Test for Solidification Point of Benzene (D 852 - 47)
Test for Color and Hydrogen Sulfide and Sulfur Dioxide Content (Qualitative) of Industrial Aromatic Hydrocarbons (D 853 - 47)

Committee E-5 on Fire Tests of Materials and Construction:

Report presented by R. C. Corson, secretary, and the following actions taken:

Accepted as Tentative:

Methods of Fire Tests of Roof Coverings (E 108 - 55 T)

Accepted as Tentative, Revisions in:

Methods of Fire Tests of Door Assemblies (E 152 - 41)

Adopted as Standard, Revisions in:

Methods of Fire Tests of Building Construction and Materials (E 119 - 54): Covering (1) adoption as standard of present tentative revision of Sections 4, 5, and 6; and (2) immediate adoption of revision of Section 3(*a*).

ELEVENTH SESSION—GILLETT MEMORIAL LECTURE

TUESDAY, JUNE 28, 5:00 P.M.

SESSION CHAIRMAN: PRESIDENT N. L. MOCHEL

Fourth Gillett Memorial Lecture:

President Mochel called upon Mr. H. C. Cross of Battelle Memorial Inst., who remarked upon the establishment of the H. W. Gillett Memorial Lecture. This lecture is sponsored jointly by the ASTM and the Battelle Memorial Inst. to perpetuate the memory of Horace W. Gillett, one of America's leading technologists, the first Director of Battelle Inst., and for many years a very active worker in the Society, through the presentation of a lecture on a subject pertaining to the development, testing, evaluation, and application of metals.

Mr. Cross introduced Fritz V. Lenel, Associate Professor, Department of Metallurgical Engineering, Rensselaer Polytechnic Inst., who presented the fourth H. W. Gillett Memorial Lecture on the subject, "Powder Metallurgy—Now (New Techniques, Improved Properties, Wider Use.)" Dr. Lenel reviewed the growth of powder metallurgy as a method of fabrication for metal products. Some of the more significant advances have been made in the field of "structural parts." The lecturer presented examples of machine parts, told how they are made, the advantages and limitations, difficulties overcome, and mechanical properties resulting. Briefly described was the production of semifabricated products, such as extrusions, forgings, sheet, rod, and wire, from powder—products which have properties superior to those made by fusion. Powder metallurgy has also found wider use in the development of materials which must have high strength when operating at elevated temperatures.

President Mochel expressed appreciation to Dr. Lenel for his outstanding lecture and presented to him on behalf of the Society the H. W. Gillett Memorial Lecture Certificate.

TWELFTH SESSION—SIGNIFICANCE OF TESTS OF CONCRETE

TUESDAY, JUNE 28, 8:00 P.M.

SESSION CHAIRMAN: H. K. COOK

Resistance of Concrete to Fire and Radiation (Including Jet-Aircraft Blast)—Perry H. Petersen, presented by K. B. Wright.[6]

Basic Considerations Pertaining to the Freezing-and-Thawing Test—T. C. Powers, presented by the author.

Needed Research on Concrete and Concrete Aggregates—A. T. Goldbeck, presented by the author.[6]

Static and Fatigue Strength of Concrete—Clyde E. Kesler and Chester P. Siess, presented by Mr. Kesler.[6]

THIRTEENTH SESSION—WATER FOR INDUSTRIAL PURPOSES

TUESDAY, JUNE 28, 8:00 P.M.

SESSION CHAIRMAN: F. N. ALQUIST

Committee D-19 on Industrial Water:

Report presented by Max Hecht, chairman, and the following actions taken:

Accepted as Tentative:

Test for Hydrazine in Industrial Water (D 1385 - 55 T)

Accepted as Tentative, Revisions in:

Methods of Sampling Industrial Water (D 510 - 54 T)
Test for Silica in Industrial Water (D 859 - 50 T)
Test for Acidity and Alkalinity in Industrial Water (D 1067 - 51 T)
Test for Iron in Industrial Water (D 1068 - 49 T)
Test for Hardness in Industrial Water (D 1126 - 53 T)
Test for Fluoride Ion in Industrial Water (D 1179 - 51 T)
Spec. for Reagent Water (D 1193 - 52 T)
Test for Chemical Oxygen Demand (Dichromate Oxygen Demand) of Industrial Waste Water (D 1252 - 53 T)
Test for Sulfides in Industrial Waste Water (D 1255 - 53 T)
Test for pH of Industrial Waste Water (D 1293 - 53 T)
Test for Chloride Ion in Industrial Water (D 512 - 49)
Test for Total Orthophosphate and Calculation of the Respective Orthophosphate Ions in Industrial Water (D 515 - 43)
Test for Sulfate Ion in Industrial Water (D 516 - 49)

Adopted as Standard:

Method of Reporting Results of Analysis of Industrial Water and Industrial Waste Water (D 596 - 54 T)
Method for Examination of Water-Formed Deposits by Chemical Microscopy (D 1245 - 52 T)
Test for Iodide and Bromide Ions in Industrial Water (D 1246 - 52 T)

Adopted as Standard, Revisions in:

Def. of Terms Relating to Industrial Water (D 1129 - 54)

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[6] Included in the volume on Significance of Tests of Concrete issued as separate publication *ASTM STP No. 169.*

Reapproval of Standards:

Test for Hydroxide Ion in Industrial Water (D 514 - 47)

Test for Manganese in Industrial Water (D 858 - 49)

Method of Field Sampling of Water-Formed Deposits (D 887 - 49)

Method of Corrosivity Test of Industrial Water (NDHA Method) (D 935 - 49)

Accepted for Publication as Information Only:

Non-Referee Method of Test for Total Orthophosphate in Industrial Water

Max Hecht Award:

The second Max Hecht Award was presented to Everett P. Partridge, Director, Hall Laboratories, Inc., Pittsburgh, Pa., at the meeting of D-19.

This award is presented in recognition of outstanding service to Committee D-19 on Industrial Water in the advancement of its objective—the study of water as an engineering material. The award was established by the committee in 1954 in honor of its first chairman, Max Hecht.

SYMPOSIUM ON HIGH PURITY WATER CORROSION[7]

Methods of Preparing and Maintaining High Purity Water—F. N. Alquist, presented by the author.

Effect of Material Composition in High-Temperature Water Corrosion—A. H. Roebuck, presented by the author.

Special Study of Carbon and Low Alloy Steels—R. U. Blaser, presented by the author.

The Influences of Water Composition on Corrosion in High-Temperature, High Purity Water—D. M. Wroughton, J. M. Seamon, and P. E. Brown, presented by Mr. Wroughton.

The Use of Water in Atomic Reactors—H. W. Huntley and S. Untermyer, presented by Mr. Huntley.

FOURTEENTH SESSION—SYMPOSIUM ON ATMOSPHERIC CORROSION OF NON-FERROUS METALS[8]

WEDNESDAY, JUNE 29, 9:30 A.M.

SESSION CO-CHAIRMEN: K. G. COMPTON
F. L. LAQUE

Introduction—K. G. Compton.

The Resistance of Aluminum-Base Alloys to 20-Year Atmospheric Exposure—C. J. Walton and William King, presented by Mr. Walton.

Effect of Marine and Urban Atmospheres on Aluminum Alloys—Fred M. Reinhart and G. A. Ellinger, presented by Mr. Reinhart.

Effect of Natural Atmospheres on Copper Alloys —20-Year Test—A. W. Tracy, presented by the author.

Atmospheric Corrosion of Copper—Results of 20-Year Test—D. H. Thompson, A. W. Tracy, and John R. Freeman, Jr., presented by Mr. Tracy.

Committee B-3 on Corrosion of Non-Ferrous Metals and Alloys:

Report presented by K. G. Compton, chairman, and accepted as a report of progress.

Advisory Committee on Corrosion:

Report presented by F. L. LaQue, chairman, and accepted as a report of progress.

Committee A-5 on Corrosion of Iron and Steel:

Report presented by A. P. Jahn, chairman, and the following actions taken:

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[7] Issued as separate publication *ASTM STP No. 179.*

[8] Issued as separate publication *ASTM STP No. 175.*

Accepted as Tentative:

Spec. for Zinc-Coated Steel Chain-Link Fence Fabric (A 392 - 55 T)

Accepted as Tentative, Revisions in:

Spec. for Zinc-Coated (Galvanized) Iron or Steel Sheets, Coils and Cut Lengths (A 93 - 53 T)
Spec. for 1.25-oz Ordered Coating (Pot Yield) Zinc-Coated (Galvanized) Iron or Steel Roofing Sheets (A 361 - 52 T)
Spec. for Overhead Ground Wire Strand (A 363 - 52 T)

Revision of Standard and Reversion to Tentative:

Spec. for Zinc-Coated (Galvanized) Iron or Steel Tie Wires (A 112 - 33)

Withdrawal of Standard:

Spec. for Zinc-Coated Iron or Steel Chain-Link Fence Galvanized After Weaving (A 117 - 33)

Withdrawal of Tentative:

Spec. for Zinc-Coated Iron or Steel Chain-Link Fence Fabric Galvanized Before Weaving (A 337 - 51 T)

Reapproval of Standards:

Spec. for Farm-Field and Railroad Right-of-Way Fencing (A 116 - 48)
Spec. for Barbed Wire (A 121 - 48)
Test for Uniformity of Coating by the Preece Test (Copper Sulfate Dip) on Zinc-Coated (Galvanized) Iron or Steel Articles (A 239 - 41)
Rec. Practice for Safeguarding Against Embrittlement of Hot Galvanized Structural Steel Products and Procedure for Detecting Embrittlement (A 143 - 46)

(*Symposium Continued in the Seventeenth Session*)

FIFTEENTH SESSION—CONCRETE

WEDNESDAY, JUNE 29, 9:30 A.M.

SESSION CHAIRMAN: L. E. GREGG

A Method for Determining the Moisture Condition of Hardened Concrete in Terms of Relative Humidity—Carl A. Menzel, presented by the author.
Osmotic Studies and Hypothesis Concerning Alkali-Aggregate Reaction—George Verbeck and Charles Gramlich, presented by Mr. Verbeck.
Effect of Depth of Beam upon Modulus of Rupture of Plain Concrete—C. P. Lindner and J. C. Sprague, presented by Mr. Sprague.

Committee C-9 on Concrete and Concrete Aggregates:

Report presented by Fred Hubbard, vice-chairman, and the following actions taken:

Accepted as Tentative:

Test for Ball Penetration in Fresh Cement Concrete (C 360 - 55 T)

Accepted as Tentative, Revisions in:

Test for Air Content (Volumetric) of Freshly Mixed Concrete (C 173 - 42 T)
Test for Water Retention Efficiency of Liquid Membrane-Forming Compounds and Impermeable Sheet Materials for Curing Concrete (C 156 - 53 T)
Test for Soundness of Aggregates by Use of Sodium Sulfate or Magnesium Sulfate (C 88 - 46 T)
Test for Potential Volume Change of Cement-Aggregate Combinations (C 342 - 54 T)
Test for Fundamental Transverse and Torsional Frequencies of Concrete Specimens (C 215 - 52 T)
Spec. for Concrete Aggregates (C 33 - 54 T)
Spec. for Ready Mixed Concrete (C 94 - 54 T)
Def. of Terms Relating to Concrete and Concrete Aggregates (C 125 - 48)
Spec. for Waterproof Paper for Curing Concrete (C 171 - 53)
Test for Unit Weight of Aggregate (C 29 - 42)
Test for Clay Lumps in Aggregates (C 142 - 39)

Adopted as Standard, Revisions in:

Method of Testing Air-Entraining Admixtures for Concrete (C 233 - 54)

Test for Abrasion of Coarse Aggregate by Use of the Los Angeles Machine (C 131 - 51) (Jointly with Committee D-4)
Test for Abrasion of Graded Coarse Aggregate by Use of the Deval Machine (D 289 - 53) (Jointly with Committee D-4)
Method of Making and Curing Concrete Compression and Flexure Test Specimens in the Field (C 31 - 49)
Method of Making and Curing Concrete Compression and Flexure Test Specimens in the Laboratory (C 192 - 54)

Reapproval of Standards:

Test for Voids in Aggregate for Concrete (C 30 - 37)
Test for Organic Impurities in Sands for Concrete (C 40 - 48)
Test for Surface Moisture in Fine Aggregate (C 70 - 47)
Test for Flexural Strength of Concrete (Using Simple Beam with Third-Point Loading) (C 78 - 49)
Test for Compressive Strength of Concrete Using Portions of Beams Broken in Flexure (Modified Cube Method) (C 116 - 49)
Test for Amount of Material Finer than No. 200 Sieve in Aggregates (C 117 - 49) (Jointly with Committee D-4)
Test for Flow of Portland-Cement Concrete by Use of the Flow Table (C 124 - 39)
Test for Specific Gravity and Absorption of Coarse Aggregate (C 127 - 42) (Jointly with Committee D-4)
Test for Specific Gravity and Absorption of Fine Aggregate (C 128 - 42) (Jointly with Committee D-4)
Test for Sieve Analysis of Fine and Coarse Aggregates (C 136 - 46) (Jointly with Committee D-4)
Test for Weight per Cubic Foot, Yield, and Air Content (Gravimetric) of Concrete (C 138 - 44)
Methods of Securing, Preparing, and Testing Specimens from Hardened Concrete for Compressive and Flexural Strengths (C 42 - 49)
Method of Measuring Length of Drilled Concrete Cores (C 174 - 49)

Sanford E. Thompson Award:

The Thirteenth Sanford E. Thompson Award was made to Richard C. Mielenz, Head, Petrographic Laboratory, Bureau of Reclamation, Denver, Colo., for his paper on "Petrographic Examination of Concrete Aggregate," presented at the 1954 Annual Meeting and published in the 1954 *Proceedings.*

Committee C-13 on Concrete Pipe:

Report presented by R. R. Litehiser, chairman, and the following actions taken:

Accepted as Tentative:

Spec. for Reinforced Concrete Low-Head Pressure Pipe (C 361 - 55 T)
Spec. for Reinforced Concrete Low-Head Internal Pressure Sewer Pipe (C 362 - 55 T)

Adopted as Standard, Revisions in:

Spec. for Concrete Sewer Pipe (C 14 - 54): Covering (1) adoption as standard of present tentative revision of Sections 2, 6, 14(*b*), 15, 17(*c*), 24, Table I, Fig. 1, and Fig. 2; and (2) immediate adoption of revision of Section 20, addition of new Section 25, revision of Table II, and Table III.
Spec. for Reinforced Concrete Sewer Pipe (C 75 - 54): Covering (1) adoption as standard of present tentative revision of Sections 7, 13, New Section 14, 23, 25, 27(*c*), 30, 31, 32(*d*), Fig. 2, and Fig. 3; and (2) immediate adoption of revision of Sections 13, 20, 32, and Table I.
Spec. for Reinforced Concrete Culvert Pipe (C 76 - 54): Covering (1) adoption as standard of present tentative revision of Sections 7, 13, New Section 14, 25, 27, 29(*c*), 32, 33, 34(*d*), Figs. 2 and 3; and (2) immediate adoption of revision of Sections 13, 21, 34, Table I, and Table II.
Spec. for Concrete Irrigation Pipe (C 118 - 52): Covering (1) adoption as standard of present tentative revision of Title, Sections 1, 2, 6, 12, 13(*a*), 15(*c*), and Fig. 1; and (2) immediate adoption of revision of Section 11 and Table I.

SESSION ON ELECTRON MICROSTRUCTURE

WEDNESDAY, JUNE 29, 10:00 A.M.

SESSION CO-CHAIRMEN: R. M. FISHER
S. T. ROSS

Subcommittee XI on Electron Microstructure of Metals of Committee E-4 on Metallography held a technical session on electron microstructure, and the following papers were presented:

Electron Microstructures of Bainite and Tempered Martensite in Steel—D. M. Teague and S. T. Ross.

Decomposition of Austenite and Martensite—A. E. Austin and C. M. Schwartz.

X-ray Diffraction Measurement of Phase Composition: Subcommittee XI Plain Carbon Steel Tempered Martensite Series—W. L. Grube and D. P. Koistinen.

Carbide Precipitation During Tempering of 1087 Steel—R. M. Fisher.[8a]

Selective Etching Technique for Identification of Gamma Phase of Nickel-Base Alloys—W. C. Bigelow and J. A. Emy.[8a]

Application of Electron Diffraction and Electron Microscopy to the Study of Minor Phases of Heat Resistant Alloys—W. C. Bigelow, L. O. Brockway, and J. W. Freeman.[8a]

[8a] Manuscript not submitted for publication.

SIXTEENTH SESSION—REPORT SESSION

WEDNESDAY, JUNE 29, 11:30 A.M.

SESSION CHAIRMAN: W. A. ZINZOW

Committee C-3 on Chemical-Resistant Mortars:

Report presented by Beaumont Thomas, chairman, and the following actions taken:

Adopted as Standard:

Test for Compressive Strength of Resin-Type Chemical Resistant Mortars (C 306 – 53 T)
Test for Tensile Strength of Resin-Type Chemical Resistant Mortars (C 307 – 53 T)
Test for Working and Setting Times of Resin-Type Chemical Resistant Mortars (C 308 – 53 T)

Committee C-11 on Gypsum:

Report presented by O. H. Storey, Jr., secretary, and the following actions taken:

Adopted as Standard:

Spec. for Gypsum Concrete (C 317 – 54 T)
Spec. for Gypsum Formboard (C 318 – 53 T)

Adopted as Standard, Revisions in:

Def. of Terms Relating to Gypsum (C 11 – 50)
Spec. for Gypsum Wallboard (C 36 – 54)

A recommendation had been inadvertently omitted from the report as preprinted for the immediate revision of the Standard Specifications for Gypsum Plaster (C 28 – 50). The revision consists of a change in Section 12 to read:

"Gypsum wood-fiber plaster shall contain not less than 66.0 per cent by weight of $CaSO_4 \cdot \frac{1}{2} H_2O$ and not less than 0.75 per cent by weight of wood-fiber made from non-staining wood when tested in accordance with ASTM Designation C 26."

Committee C-19 on Structural Sandwich Constructions:

Report presented in the absence of the chairman by R. E. Hess, and the following actions taken:

Accepted as Tentative:

Test for Flatwise Compressive Strength of Sandwich Cores (C 365 – 55 T)
Test for Edgewise Compressive Strength of Flat Sandwich Construction (C 364 – 55 T)
Test for Delamination Strength of Honeycomb Type Core Material (C 363 – 55 T)

Methods for Measurement of Thickness of Sandwich Cores (C 366 - 55 T)

Adopted as Standard:

Method of Tension Test in Flatwise Plane of Sandwich Constructions (C 297 - 52 T)

Committee D-5 on Coal and Coke:

Report presented by W. W. Anderson, chairman, and the following action taken:

Accepted as Tentative, Revisions in:

Methods of Laboratory Sampling and Analysis of Coal and Coke (D 271 - 48)

Committee D-7 on Wood:

Report presented by L. J. Markwardt, chairman, and the following actions taken:

Accepted as Tentative, Revisions in:

Methods of Static Tests of Wood Poles (D 1036 - 49 T)
Test for Alpha-Cellulose in Cellulosic Materials (D 1103 - 50 T)
Methods of Evaluating the Properties of Fiber Building Boards (D 1037 - 52 T) with the withdrawal from the report as preprinted of the revision of Section 11, and the insertion in Section 28 of the sentence: "The test specimen shall be 2 in. (5 cm) square and the thickness shall be that of the finished board."
Test for Methoxyl Groups in Wood and Related Materials (D 1166 - 51 T)

Adopted as Standard:

Spec. for Round Timber Piles (D 25 - 54 T)

Adopted as Standard, Revisions in:

Spec. for Creosoted End-Grain Wood Block Flooring for Interior Use (D 1031 - 51)

Committee D-14 on Adhesives:

Report presented in the absence of the chairman by R. E. Hess, and the following actions taken:

Accepted as Tentative:

Test for Susceptibility of Dry Adhesive Films to Attack by Roaches (D 1382 - 55 T)
Test for Susceptibility of Dry Adhesive Films to Attack by Laboratory Rats (D 1383 - 55 T)

Accepted as Tentative, Revisions in:

Test for Consistency of Adhesives (D 1084 - 50 T)
Test for Resistance of Adhesives for Wood to Cyclic Accelerated Service Conditions (D 1183 - 51 T)
Def. of Terms Relating to Adhesives (D 907 - 52)

Adopted as Standard:

Test for Effect of Bacterial Contamination on Permanence of Adhesive Preparations and Adhesive Bonds (D 1174 - 51 T)
Test for Strength of Adhesives on Flexural Loading (D 1184 - 51 T)

Adopted as Standard, Revisions in:

Def. of Terms Relating to Adhesives (D 907 - 52), with the withdrawal from the report as preprinted of the recommendation for the adoption as standard of the tentative definition for "adhesive dispersion."

Reapproval of Standards:

Test for Tensile Properties of Adhesives (D 897 - 49)
Test for Peel or Stripping Strength of Adhesives (D 903 - 49)
Test for Strength Properties of Adhesives in Shear by Compression Loading (D 905 - 49)
Test for Strength Properties of Adhesives in Plywood Type Construction in Shear by Tension Loading (D 906 - 49)

Committee D-17 on Naval Stores:

Report presented by V. E. Grotlisch, chairman, and the following actions taken:

Accepted as Tentative, Revisions in:

Def. of Terms Relating to Naval Stores and Related Products (D 804 - 52)

Adopted as Standard, Revisions in:

Methods of Sampling and Grading Rosin (D 509 - 52)

Reapproval of Standards:

Methods of Sampling and Testing Dipentene (D 801 - 48)
Methods of Sampling and Testing Pine Oil (D 802 - 49)
Methods of Sampling and Testing Pine Tars and Pine-Tar Oils (D 856 - 49)

Accepted for Publication as Information Only:

Test for Crystallization Tendency of Gum Rosin
Method of Testing Tall Oil Skimmings

SEVENTEENTH SESSION—SYMPOSIUM ON ATMOSPHERIC CORROSION OF NON-FERROUS METALS[8]

(*Symposium Continued from Fourteenth Session*)

WEDNESDAY, JUNE 29, 2:00 P.M.

SESSION CHAIRMAN: C. P. LARRABEE

Atmospheric Galvanic Corrosion of Dissimilar Metal Couples—H. O. Teeple, presented by the author.

Galvanic Couple Corrosion Studies by Means of the Threaded Spool and Wire Test—K. G. Compton and A. Mendizza, presented by Mr. Compton.

The Atmospheric Corrosion of Rolled Zinc—E. A. Anderson, presented by the author.

The Behavior of Lead, Tin, and Antimonial Lead in the Outdoor Atmosphere—George O. Hiers and E. J. Minarcik, presented by Mr. Minarcik.

Atmospheric Corrosion Behavior of Some Nickel Alloys—H. R. Copson, presented by the author.

EIGHTEENTH SESSION—SYMPOSIUM ON SPEED OF TESTING[9]

WEDNESDAY, JUNE 29, 2:00 P.M.

SESSION CHAIRMAN: F. M. HOWELL

Effect of Speed of Testing on Tensile Strength and Elongation of Paper—Ralph E. Green, presented by the author.

Effect of Speed in Plastics Testing—F. J. McGarry and Albert G. H. Dietz, presented by Mr. McGarry.

The Influence of Rate of Loading on the Strength of Wood and Wood-Base Materials—L. J. Markwardt and J. A. Liska, presented by Mr. Markwardt.

Stress-Strain Relationships in Yarns Subjected to Rapid Impact Loading—Herbert F. Schiefer, Jack C. Smith, Frank L. McCrackin, and Walter K. Stone, presented by Mr. Schiefer.

Effect of Speed in Mechanical Testing of Concrete—J. J. Shideler and Douglas McHenry, presented by Mr. McHenry.

The Effect of Speed of Testing on Glass—H. N. Ritland, presented by the author.

Effect of Speed of Testing on Tension Test of Elastomers and Hard Rubber—D. C. Scott, Jr., and D. S. Villars, presented by Mr. Villars.

Constant Strain Rate Test of Plastics—George Rugger, presented by the author.

Committee E-1 on Methods of Testing:

Report presented by J. R. Townsend, chairman, and the following actions taken:

Accepted as Tentative:

Method for Determination of Young's Modulus at Room Temperature (E 111 - 55 T)

Test for Indentation Hardness of Metallic Materials by Portable Hardness Testers (E 110 - 55 T)

Accepted as Tentative, Revisions in:

Methods of Verification of Testing Machines (E 4 - 50 T)

Methods of Verification of Calibration Devices for Verifying Testing Machines (E 74 - 50 T)

Test for Rockwell Hardness and Rockwell Superficial Hardness of Metallic Materials (E 18 - 54)

Adopted as Standard:

Method for Diamond Pyramid Hardness of Metallic Materials (E 92 - 52 T)

Adopted as Standard, Revisions in:

Spec. for ASTM Thermometers (E 1 - 54)

The committee withdrew from the report as preprinted the recommendation for adoption as standard of the Tentative Methods of Compression Testing of Metallic Materials (E 9 - 52 T).

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[9] Issued as separate publication *STP No. 185.*

PAPER ON TESTING BUILDING CONSTRUCTIONS

WEDNESDAY, JUNE 29, 2:00 P.M.

At an open meeting of Committee E-6 on Methods of Testing Building Constructions, the following paper was presented:

A Philosophy of Loading Tests for Structures—W. R. Schriever and D. B. Dorey.[10]

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[10] Published in the ASTM BULLETIN, No. 214, May, 1956.

PAPER ON SOILS

WEDNESDAY, JUNE 29, 2:30 P.M.

At the conclusion of the business meeting of Committee D-18 on Soils for Engineering Purposes, the following paper was presented:

The Relationship Between Water Content and the Accuracy with Which In-Place Densities of Sands May Be Measured—Donald F. Griffin.[11]

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[11] Published in the ASTM BULLETIN, No. 212, February, 1956, p. 51 (TP 39).

NINETEENTH SESSION—REPORT SESSION

WEDNESDAY, JUNE 29, 4:00 P.M.

SESSION CO-CHAIRMEN: PRESIDENT N. L. MOCHEL
E. F. LUNDEEN

Committee A-1 on Steel:

Report presented by H. B. Oatley, chairman, and the following actions taken:

Accepted as Tentative:

Rec. Practices for Ultrasonic Testing and Inspection of Heavy Steel Forgings (A 388 - 55 T)
Spec. for Chromium-Molybdenum Steel Plates for Boilers and Other Pressure Vessels (A 387 - 55 T)
Spec. for Alloy Steel Castings Normalized and Drawn for High Pressure and Elevated Temperature Service (A 389 - 55 T)
Spec. for Alloy Steel Chain (A 391 - 55 T)

Accepted as Tentative, Revisions in:

Spec. for Steel for Bridges and Buildings (A 7 - 53 T)
Spec. for Welded and Seamless Steel Pipe (A 53 - 54 T)
Spec. for Seamless Steel Boiler Tubes (A 83 - 54 T)
Spec. for Seamless Carbon-Steel Pipe for High-Temperature Service (A 106 - 52 T)
Spec. for Electric-Resistance-Welded Steel Pipe (A 135 - 54 T)
Spec. for Electric-Fusion-Welded Steel Pipe for High Temperature Service (A 155 - 52a T)
Spec. for Seamless Low-Carbon and Carbon-Molybdenum Steel Still Tubes for Refinery Service (A 161 - 54 T)
Spec. for Electric-Resistance-Welded Steel and Open-Hearth Iron Boiler Tubes (A 178 - 54 T)
Spec. for Seamless Cold-Drawn Intermediate Alloy-Steel Heat-Exchanger and Condenser Tubes (A 199 - 54 T)
Spec. for Seamless Intermediate Alloy-Steel Still Tubes for Refinery Service (A 200 - 54 T)
Spec. for Seamless Carbon-Molybdenum Alloy-Steel Boiler and Superheater Tubes (A 209 - 54 T)
Spec. for Medium-Carbon Seamless Steel Boiler and Superheater Tubes (A 210 - 54 T)
Spec. for Seamless Alloy Steel Boiler, Superheater, and Heat Exchanger Tubes (A 213 - 54 T)

Spec. for Electric-Resistance-Welded Steel Heat-Exchanger and Condenser Tubes (A 214 - 54 T)

Spec. for Electric-Resistance-Welded Steel Boiler and Superheater Tubes for High-Pressure Service (A 226 - 54 T)

Spec. for Welded Austenitic Stainless Steel Boiler, Superheater, Heat Exchanger and Condenser Tubes (A 249 - 54 T)

Spec. for Electric-Resistance-Welded Carbon-Molybdenum Alloy-Steel Boiler and Superheater Tubes (A 250 - 54 T)

Spec. for Welded and Seamless Open-Hearth Iron Pipe (A 253 - 54 T)

Spec. for Copper Brazed Steel Tubing (A 254 - 54 T)

Spec. for Low and Intermediate Tensile Strength Carbon Silicon Steel Plates for Machine Parts and General Construction (A 284 - 52 T)

Spec. for Carbon and Alloy-Steel Forgings for Turbine Rotors and Shafts (A 293 - 52 T)

Spec. for Carbon-Steel Bars Subject to Mechanical Property Requirements (A 306 - 52a T)

Spec. for Seamless and Welded Austenitic Stainless Steel Pipe (A 312 - 54 T) (Jointly with Committee A-10)

Spec. for Alloy-Steel Bolting Materials for Low-Temperature Service (A 320 - 53 T), with the withdrawal from the report as preprinted of the recommendation that grade L86 be added to the specification.

Spec. for Seamless and Welded Steel Pipe for Low-Temperature Service (A 333 - 54 T)

Spec. for Seamless and Welded Steel Tubes for Low-Temperature Service (A 334 - 54 T)

Spec. for Seamless Ferritic Alloy-Steel Pipe for High-Temperature Service (A 335 - 53 T)

Spec. for Alloy-Steel Seamless Drum Forgings (A 336 - 51 T)

Spec. for Ferritic Steel Castings for Pressure Containing Parts Suitable for Low-Temperature Service (A 352 - 52 T)

Spec. for Electric-Fusion-Welded Austenitic Chromium-Nickel Alloy Steel Pipe for High Temperature Service (A 358 - 52 T)

Spec. for Ferritic Alloy-Steel Forged and Bored Pipe for High-Temperature Service (A 369 - 53 T)

Spec. for Carbon and Alloy-Steel Forgings for Pressure Vessel Shells (A 372 - 53 T)

Spec. for Seamless Austenitic Steel Pipe for High-Temperature Central-Station Service (A 376 - 54 T)

Spec. for Forged or Rolled Steel Pipe Flanges, Forged Fittings, and Valves and Parts for High-Temperature Service (A 105 - 46), with the withdrawal from the report as preprinted of the revision of Section 6.

Spec. for Forged or Rolled Steel Pipe Flanges, Forged Fittings, and Valves and Parts for General Service (A 181 - 49), with the withdrawal from the report as preprinted of the revision of Section 5.

Adopted as Standard:

Spec. for Mild- to Medium-Strength Carbon-Steel Castings for General Application (A 27 - 52 T)

Spec. for Quenched Carbon-Steel Joint Bars (A 49 - 53 T)

Spec. for Low-Carbon Steel Track Bolts and Nuts (A 76 - 49 T)

Spec. for Structural Steel for Ships (A 131 - 53 T)

Spec. for Structural Rivet Steel (A 141 - 52 T)

Spec. for High-Strength Steel Castings for Structural Purposes (A 148 - 50 T)

Spec. for Heat-Treated Carbon and Alloy Steel Track Bolts and Carbon Steel Nuts (A 183 - 53 T)

Spec. for Alloy-Steel Castings for Pressure Containing Parts Suitable for High-Temperature Service (A 217 - 49 T)

Spec. for High Strength Low Alloy Structural Steel (A 242 - 53 T)

Spec. for Forged or Rolled Carbon and Alloy Steel Flanges, Forged Fittings, and Valves and Parts for Low-Temperature Service (A 350 - 52 T)

Spec. for Boiler Rivet Steel and Rivets (A 31 - 52 T)

The committee withdrew from the report as preprinted the recommendation for the adoption as standard of Tentative Specifications for High-Strength Structural Rivet Steel (A 195 - 52 T)

Adopted as Standard, Revisions in:

Spec. for Electric-Fusion (Arc)-Welded Steel Pipe (Sizes 4 in. and Over) (A 139 - 54), with a revision in requirements of Table I.

Spec. for Carbon Steel Forgings for General Industrial Use (A 235 - 54)

Spec. for Carbon Steel Forgings for Railway Use (A 236 - 54)

Spec. for Alloy-Steel Forgings for General Industrial Use (A 237 - 54)

Spec. for Alloy-Steel Forgings for Railway Use (A 238 - 54)

Spec. for Carbon and Alloy-Steel Ring and Disk Forgings (A 243 - 54)

Spec. for Carbon Steel Seamless Drum Forgings (A 266 - 54)

Spec. for Seamless and Welded Ferritic Stainless

Steel Tubing for General Service (A 268 - 54) (Jointly with Committee A-10)
Spec. for Seamless and Welded Austenitic Stainless Steel Tubing for General Service (A 269 - 54) (Jointly with Committee A-10)
Spec. for Seamless and Welded Austenitic Stainless Steel Sanitary Tubing (A 270 - 54) (Jointly with Committee A-10)
Spec. for Seamless Austenitic Chromium-Nickel Steel Still Tubes for Refinery Service (A 271 - 54) (Jointly with Committee A-10).
Spec. for Carbon and Alloy-Steel Forgings for Magnetic Retaining Rings for Turbine Generators (A 288 - 54)
Spec. for Alloy-Steel Forgings for Nonmagnetic Coil Retaining Rings for Turbine Generators (A 289 - 54)
Spec. for Carbon and Alloy-Steel Forgings for Rings for Reduction Gears (A 290 - 54)
Spec. for Carbon and Alloy-Steel Forgings for Pinions for Reduction Gears (A 291 - 54)
Spec. for Carbon and Alloy-Steel Forgings for Turbine Generator Rotors and Shafts (A 292 - 54)
Spec. for Carbon and Alloy-Steel Forgings for Turbine Bucket Wheels (A 294 - 54)

Special permission was obtained from the Executive Committee of the Board of Directors to add a recommendation for the revision, immediate adoption, of Standard Specifications for Welded and Seamless Steel Pipe Piles (A 252 - 54). The revision is as follows:

Section 1.—Delete the Note referring to Methods A 370.[3]

Section 3.—Revise Paragraph (*b*) to read as follows:

"The yield point shall be determined by the drop of the beam, by the halt in the gage of the testing machine, by the use of dividers, or by other approved methods. When a definite yield point is not exhibited, the yield strength corresponding to a permanent offset of 0.2 per cent of the gage length of the specimen, or to a total extension of 0.5 per cent of the gage length under load shall be determined."

Section 4.—Change title to read "Test Specimens and Methods of Testing" and add a new Paragraph (*a*) to read as follows, relettering subsequent paragraphs accordingly:

"(*a*) The test specimens and the tests required by these specifications shall conform to those described in the Methods and Definitions for the Mechanical Testing of Steel Products (ASTM Designation: A 370).[3]"

Reapproval of Standards:

Spec. for Steel Tires (A 26 - 39)
Spec. for Low Carbon Steel Tie Plates (A 67 - 48)
Spec. for Hot-Worked High-Carbon Steel Tie Plates (A 241 - 48)
Spec. for Wrought Steel Wheels for Electric Railway Service (A 25 - 48)
Methods of Magnetic Particle Testing and Inspection of Heavy Steel Forgings (A 275 - 47)

The committee withdrew from the preprinted report the recommendation for the reapproval of Standard Specifications for Carbon-Steel Castings for Valves, Flanges, and Fittings for High-Temperature Service (A 95 - 44), and added the above recommendation for the reapproval of Standard Methods A 275 - 47.

Committee A-7 on Malleable Iron Castings:

Report presented by W. A. Kennedy, chairman, and the following action taken:

Accepted as Tentative, Revisions in:

Spec. for Pearlitic Malleable Iron Castings (A 220 - 51), with the further revision in Table I of the addition of Grade 53004 which is subject to letter ballot approval of Committee A-7.

Committee A-10 on Iron-Chromium, Iron-Chromium-Nickel, and Related Alloys:

Report presented by Jerome Strauss, chairman, and the following actions taken:

Accepted as Tentative:

Rec. Practice for Conducting Acidified Copper Sulfate Test for Intergranular Attack in Austenitic Stainless Steel (A 393 - 55 T)

Accepted as Tentative, Revisions in:

Rec. Practice for Boiling Nitric Acid Test for Corrosion-Resisting Steels (A 262 - 52 T)
Spec. for Seamless and Welded Austenitic Stainless Steel Pipe (A 312 - 54 T) (Jointly with Committee A-1)

Adopted as Standard:

Spec. for Corrosion-Resistant Iron-Chromium and Iron-Chromium-Nickel Alloy Castings for General Application (A 296 - 49 T)
Spec. for Heat-Resistant Iron-Chromium and Iron-Chromium-Nickel Alloy Castings for General Application (A 297 - 49 T)
Spec. for Chromium-Nickel Corrosion-Resisting Steel Spring Wire (A 313 - 47 T)
Spec. for Corrosion-Resisting Steel Billets and Bars for Reforging (A 314 - 47 T)
Spec. for Stainless Steel Wire Strand (A 368 - 53 T)

Adopted as Standard, Revisions in:

Spec. for Hot-Rolled and Cold-Finished Corrosion-Resisting Steel Bars (A 276 - 54)
Spec. for Seamless and Welded Ferritic Stainless Steel Tubing for General Service (A 268 - 54) (Jointly with Committee A-1)
Spec. for Seamless and Welded Austenitic Stainless Steel Tubing for General Service (A 269 - 54) (Jointly with Committee A-1)
Spec. for Seamless and Welded Austenitic Stainless Steel Sanitary Tubing (A 270 - 54) (Jointly with Committee A-1)
Spec. for Seamless Austenitic Chromium-Nickel Steel Still Tubes for Refinery Service (A 271 - 54) (Jointly with Committee A-1)

Committee B-6 on Die-Cast Metals and Alloys:

Report presented by W. Babington, chairman, and accepted as a report of progress.

Committee E-3 on Chemical Analysis of Metals:

Report presented by Arba Thomas, chairman, and the following actions taken:

Reapproval of Standards:

Methods for Chemical Analysis of Ferro-Alloys (E 31 - 47)
Methods of Sampling Ferro-Alloys (E 32 - 42)
Methods for Chemical Analysis of Aluminum and Aluminum-Base Alloys (E 34 - 49)
Methods for Chemical Analysis of Magnesium and Magnesium-Base Alloys (E 35 - 49)
Methods for Chemical Analysis of Brasses (E 36 - 45)
Methods for Chemical Analysis of Nickel-Chromium-Iron Alloys (E 38 - 48)
Methods for Chemical Analysis of Nickel (E 39 - 45)
Methods for Chemical Analysis of Copper (E 53 - 48)
Methods for Chemical Analysis of Special Brasses and Bronzes (E 54 - 49)
Methods for Sampling Wrought Non-Ferrous Metals and Alloys for Determination of Chemical Composition (E 55 - 48)
Methods for Chemical Analysis of Silver Solder (E 56 - 45)
Methods for Sampling Steel, Cast Iron, Open-Hearth Iron and Wrought Iron (E 59 - 45)

Committee E-4 on Metallography:

Report presented by R. E. Penrod, vice-chairman, and accepted as a report of progress.

Committee E-6 on Methods of Testing Building Constructions:

Report presented by R. F. Legget, chairman, and the following actions taken:

Adopted as Standard:

Rec. Practice for the Laboratory Measurement of Airborne-Sound Transmission Loss of Building Floors and Walls (E 90 - 50 T)

Adopted as Standard, Revisions in:

Methods of Conducting Strength Tests of Panels for Building Construction (E 72 - 54)

TWENTIETH SESSION—REPORT SESSION

WEDNESDAY, JUNE 29, 4:00 P.M.

SESSION CHAIRMAN: R. T. KROPF

Committee D-1 on Paint, Varnish, Lacquer, and Related Products:

Report presented by W. T. Pearce, chairman, and the following actions taken:

Accepted as Tentative:

Test for Spectrophotometric Diene Value of Dehydrated Castor Oil and Its Derivatives (D 1358 - 55 T)
Test for No-Smear Time of Traffic Paint (D 1359 - 55 T)
Test for Fire Retardency of Paints (Cabinet Method) (D 1360 - 55 T)
Test for Fire Retardency of Paints (Stick and Wick Method) (D 1361 - 55 T)
Test for Alcohol in Methyl Isobutyl Ketone (D 1362 - 55 T)
Test for Permanganate Time of Lacquer Solvents and Diluents (D 1363 - 55 T)
Test for Water in Lacquer Solvents and Diluents (Fischer Reagent Titration Method) (D 1364 - 55 T)
Test for Color Difference Using the Hunter Color Difference Meter (D 1365 - 55 T)
Rec. Practice for Reporting Particle Size Characteristics of Pigments (D 1366 - 55 T)

Accepted as Tentative, Revisions in:

Test for Asphalt Emulsions for Use as Protective Coatings for Metal (D 1010 - 49 T) (Jointly with Committee D-8)
Method for Calculating Small Color Differences from Data Obtained on the Hunter Multipurpose Reflectometer (D 1260 - 53 T)
Test for Flash Point of Volatile Flammable Materials by Tag Open-Cup Apparatus (D 1310 - 54 T)
Spec. for Dehydrated Castor Oil (D 961 - 53 T)
Spec. for Methyl Isobutyl Ketone (D 1153 - 51 T)
Spec. for Acetone (D 329 - 33)
Test for Tinting Strength of White Pigments (D 332 - 36)
Def. of Terms Relating to Paint, Varnish, Lacquer, and Related Products (D 16 - 52).

This recommendation was listed in error in the preprinted report as a revision for adoption as standard.

Adopted as Standard:

Spec. for Wood to be Used as Panels in Weathering Tests of Paints and Varnishes (D 358 - 51 T)
Spec. for High Gravity Glycerine (D 1257 - 53 T)
Methods of Sampling and Testing High-Gravity Glycerine (D 1258 - 53 T)
Test for Solvent Tolerance of Amine Resins (D 1198 - 52 T)
Test for Residual Odor of Lacquer Solvents and Diluents (D 1296 - 53 T)
Methods of Chemical Analysis of White Lead Pigments (D 1301 - 53 T), replacing Sections 6 to 18 of the General Methods D 34.
Single and Multi-Panel Forms for Recording Results of Exposure Tests of Paints (D 1150 - 51 T)

The Standard Method of Test for Color of Clear Liquids (Platinum-Cobalt Scale) (D 1209 - 54) was listed in error in the preprinted report.

Adopted as Standard, Revisions in:

Spec. for Raw Tung Oil (D 12 - 48)
Spec. for Raw Linseed Oil (D 234 - 48)
Spec. for Boiled Linseed Oil (D 260 - 48)
Spec. for Oiticica Oil (Permanently Liquid) (D 601 - 46)
Spec. for Dry Bleached Shellac (D 207 - 49)
Spec. for Orange Shellac and Other Lacs (D 237 - 48)
Spec. for Shellac Varnishes (D 360 - 51)
Test for Consistency of Exterior House Paints and Enamel-Type Paints (D 562 - 47)
Test for No-Pick-Up Time of Traffic Paint (D 711 - 52)

Withdrawal of Standards:

Spec. for Pure Linseed Oil Putty for Glazing (D 317 - 33)
Test for Daylight 45-deg, 0-deg Luminous Directional Reflectance of Paint Finishes (D 771 - 47)

Reapproval of Standards:

Test for Nitrocellulose Clear Lacquers and Lacquer Enamels (D 333 - 40)
Test for Spectral Characteristics and Color of Objects and Materials (D 307 - 44)
Spec. for Industrial 90 Benzene for Use in Paint, Varnish, Lacquer, and Related Products (D 361 - 36)
Spec. for Industrial Grade Toluene for Use in Paint, Varnish, Lacquer, and Related Products (D 362 - 36)
Spec. for Tricresyl Phosphate (D 363 - 49)
Spec. for Industrial Grade Xylene or Solvent Naphtha for Use in Paint, Varnish, Lacquer, and Related Products (D 364 - 36)

Accepted for Publication as Information Only:

Test for Nonvolatile Content of Heat-Unstable Resin Solutions by Foil Method
Methods for Analysis of Polyvinyl Butyral

Committee D-12 on Soaps and Other Detergents:

Report presented in the absence of the chairman by P. J. Smith, and the following actions taken:

Accepted as Tentative:

Methods for Analysis of Sodium Triphosphate (D 501 - 55 T)
Method of Aerated Total Immersion Corrosion Test for Metal Cleaners (D 1374 - 55 T)

Accepted as Tentative, Revisions in:

Spec. for Trisodium Phosphate (D 538 - 44)
Spec. for Sodium Metasilicate (D 537 - 41)
Spec. for Soda Ash (D 458 - 39)

Adopted as Standard:

Methods for Analysis of Sodium Bicarbonate (D 501 - 53 T)
Spec. for Milled Toilet Soap (D 455 - 53 T)

Adopted as Standard, Revisions in:

Methods of Chemical Analysis of Sulfonated and Sulfated Oils (D 500 - 45)
Def. of Terms Relating to Soaps and Other Detergents (D 459 - 54)

Reapproval of Standards:

Spec. for White Floating Toilet Soap (D 499 - 48)

Spec. for Built Soap, Powdered (D 533 - 44)

Spec. for Alkaline Soap Powder (D 534 - 42)

Spec. for Olive Oil Solid Soap (Type A, Straight; Type B, Blended) (D 592 - 42)

Spec. for Salt-Water Soap (D 593 - 42)

Spec. for Olive Oil Chip Soap (Type A, Straight; Type B, Blended) (D 630 - 52)

Spec. for Compound Chip Soap (With Rosin) (D 690 - 48)

Spec. for Compound Powdered Soap (Granulated with Rosin) (D 691 - 44)

Spec. for Caustic Soda (Anhydrous) (D 456 - 39)

Spec. for Modified Soda (Sesquicarbonate Type) (D 457 - 39)

Spec. for Sodium Sesquisilicate (D 594 - 41)

Spec. for Tetrasodium Pyrophosphate (Anhydrous) (D 595 - 45)

Test for Particle Size of Soaps and Other Detergents (D 502 - 39)

Method of Chemical Analysis of Soaps Containing Synthetic Detergents (D 820 - 46)

Methods of Chemical Analysis of Industrial Metal Cleaning Compositions (D 800 - 45)

Methods of Total Immersion Corrosion Test of Water Soluble Aluminum Cleaners (D 930 - 49)

Committee D-13 on Textile Materials:

Report presented by W. D. Appel, chairman, and the following actions taken:

Accepted as Tentative:

Test for Pilling Propensity of Textile Fabrics (D 1375 - 55 T)

Methods of Testing Warp Knit Fabrics (D 1376 - 55 T)

Methods of Testing Wide Elastic Fabrics (D 1377 - 55 T)

Test for Absorbency Time and Absorptive Capacity of Nonwoven Fabrics (D 1378 - 55 T)

Test for Abrasion Resistance of Textile Yarns (D 1379 - 55 T)

Spec. and Methods of Test for Fineness of Mohair Tops (D 1381 - 55 T)

Test for Fineness of Cotton Fibers by Resistance to Air Flow (Arealometer) (D 1449 - 55 T)

Test for Maturity of Cotton Fibers (Polarized-Light Method) (D 1450 - 55 T)

The report also contained reference to the publication as tentative of Methods of Testing Spun and Filament Yarns Made Wholly or in Part of Man-Made Organic Base Fibers, to supersede Methods of Testing Continuous Filament Man-Made Organic Base Yarns (D 258 - 52 T), Methods of Testing and Tolerances for Spun Rayon and Acetate Yarns and Threads (D 507 - 44), and Methods of Testing and Tolerances for Yarns Spun from Mixed Fibers (D 508 - 43). This recommendation will be presented to the Administrative Committee on Standards after completion of the letter ballot in the committee.

Accepted as Tentative, Revisions in:

Spec. and Methods of Test for Fineness of Wool Tops (D 472 - 53 T)

Test for Fineness of Wool (D 419 - 50 T)

Test for Resistance of Pile Floor Coverings to Insect Pest Damage (D 1116 - 50 T)

Methods of Core Sampling of Raw Wool in Packages for Determination of Percentages of Clean Wool Fiber Present (D 1060 - 54 T)

Test for Abrasion Resistance of Textile Fabrics (D 1175 - 51 T)

Methods of Testing Pile Floor Coverings (D 418 - 42)

Methods of Testing and Tolerances for Certain Wool and Part Wool Fabrics (D 462 - 53)

Def. of Terms Relating to Textile Materials (D 123 - 54)

Test for Fiber Length of Wool (D 519 - 49)

The recommendation for the revision of Tentative Methods D 885 was withdrawn from the report as preprinted, since these changes were accepted at the 1954 Annual Meeting.

Adopted as Standard:

Def. of Terms Relating to Textile Materials (D 123 - 54), comprising adoption of definitions for 12 terms as set forth in the preprinted report, now appearing as tentative in Standard D 123 - 54.

General Methods of Testing Cotton Fiber (D 414 - 54 T): The method for length of fiber array in Sections 4 to 10 of Methods D 414 - 54 T were recommended by the committee for revision and adoption as standard and publication as Standard Method of Test for Length and Length Distribution of Cotton Fibers by the Array Method (D 1440 - 55).

Adopted as Standard, Revisions in:

Def. of Terms Relating to Textile Materials (D 123 - 54)

Test for Colorfastness to Light of Textiles (D 506 - 54)

Withdrawal of Tentative:

General Methods of Testing Cotton Fibers (D 414 - 54 T)

Accepted for Publication as Information Only:

Test for Linear Density of Textile Fibers by the Vibroscope

Test for Cotton Content of Asbestos Textile Materials (Referee Method)
Method for Analysis of Asbestos-Glass Fiber Textile Materials. This method was inadvertently listed for publication as tentative in the preprinted report.

Editorial Changes:

Standard Methods of Quantitative Analysis of Textiles (D 629 – 54)
Standard Specifications and Methods of Test for Asbestos Yarns (D 299 – 54), for Asbestos Tape for Electrical Purposes (D 315 – 52), for Asbestos Roving for Electrical Purposes (D 375 – 52), and for Asbestos Lap (D 1061 – 54)

Committee D-21 on Wax Polishes and Related Materials:

Report presented in the absence of the chairman by P. J. Smith, and the following action taken:

Accepted as Tentative, Revisions in:

Test for Nonvolatile Matter (Total Solids) in Water Emulsion Waxes (D 1289 – 53 T)

Committee D-23 on Cellulose and Cellulose Derivatives:

Report presented in the absence of the chairman by P. J. Smith, and the following actions taken:

Accepted as Tentative, Revisions in:

Test for Acetyl and Butyryl Content of Cellulose Acetate Butyrate (D 817 – 49) (Jointly with Committee D-20)

Accepted for Publication as Information Only:

Test for Viscosity of Sodium Carboxymethyl Cellulose
Test for Degree of Etherification of Sodium Carboxymethyl Cellulose

Committee E-11 on Quality Control of Materials:

Report presented from manuscript in the absence of the chairman by P. J. Smith, and accepted as a report of progress.

Committee E-12 on Appearance:

Report presented in the absence of the chairman by P. J. Smith, and the following action taken:

Adopted as Standard:

Test for 45-deg, 0-deg, Directional Reflectance of Opaque Specimens by Filter Photometry (E 97 – 53 T), with the addition of the following Note 3 to Section 2:

"NOTE 3.—Blue light reflectance by this method differs slightly, both spectrally and geometrically, from the TAPPI methods for paper and pulp brightness."

Committee D-9 on Electrical Insulating Materials:

Report presented by H. K. Graves, vice-chairman, and the following actions taken:

Accepted as Tentative:

Rec. Practice for Cleaning Plastic Specimens for Insulation Resistance Testing (D 1371 – 55 T). This recommended practice was inadvertently listed in the preprinted report as a revision of Tentative Methods D 257 – 54 T.

Accepted as Tentative, Revisions in:

Methods of Testing Varnished Cloths and Varnished Cloth Tapes Used for Electrical Insulation (D 295 – 54 T)
Methods of Testing Pressure-Sensitive Adhesive Tapes Used for Electrical Insulation (D 1000 – 53 T)
Spec. for Phenolic Molding Compounds (D 700 – 54 T) (Jointly with Committee D-20)
Spec. for Laminated Thermosetting Materials (D 709 – 54 T) (Jointly with Committee D-20)
Methods of Testing Askarels (D 901 – 53 T). This revision of Methods D 901 was listed as a new tentative in the preprinted report but is intended to replace Sections 46 to 50 of Methods D 901.
Methods of Testing Flexible Varnished Tubing Used for Electrical Insulation (D 350 – 48)
Test for Dielectric Breakdown Voltage and Dielectric Strength of Electrical Insulating Materials at Commercial Power Frequencies (D 149 – 44)

Adopted as Standard:

Spec. for Black Bias-Cut Varnished Cloth and Varnished Cloth Tape Used for Electrical Insulation (D 373 – 51 T)
Method of Testing Varnishes Used for Electrical Insulation (D 115 – 52a T)

The committee withdrew from the report as preprinted the recommendation for the reapproval of Standard Methods of Test for Conducting Paths in Slate (D 273 – 40).

TWENTY-FIRST SESSION—MARBURG LECTURE* AND TEMPLIN AWARD

WEDNESDAY, JUNE 29, 4:30 P.M.

SESSION CHAIRMAN: PRESIDENT N. L. MOCHEL

Edgar Marburg Lecture:[11a]

President Mochel opened the session by giving a brief statement of the purpose of the lecture. W. J. Hamburger, Director, Fabric Research Laboratories, Inc., was then introduced as the 29th Edgar Marburg Lecturer. Speaking on the subject, "A Technology for the Analysis, Design, and Use of Textile Structures as Engineering Materials," Dr. Hamburger traced the textile craftsmanship from its beginnings in antiquity through the industrial revolution to the present, with particular emphasis on the last decade. He examined the newest techniques and equipment employed in the analysis of textiles, mentioning the behavior of textiles in tension, compression, bending, and torsion. Also discussed were the effects of structural order upon the physical properties of fiber, the effects of fiber properties upon yarn behavior, the effects of geometry upon fabric behavior, and the importance of these behavior characteristics upon objective and subjective functional performance characteristics of textile structures.

President Mochel expressed appreciation to Dr. Hamburger for his excellent lecture and presented to him on behalf of the Society the Edgar Marburg Lecture Certificate.

Richard L. Templin Award:

The Tenth Richard L. Templin Award was made to M. S. Hunter and W. G. Fricke, Jr., Aluminum Company of America, New Kensington, Pa., for their paper on "Metallographic Aspects of Fatigue Behavior of Aluminum," presented at the 1954 Annual Meeting and published in the 1954 *Proceedings*.

[11a] Manuscript not as yet available for publication. The 1955 Marburg Lecture, therefore, will be published in separate pamphlet form.

TWENTY-SECOND SESSION—PANEL ON PYROMETRY[12]

THURSDAY, JUNE 30, 9:30 A.M.

SESSION CHAIRMAN: J. J. KANTER

A panel Session on Pyrometric Practice in Elevated Temperature Testing, sponsored by the Joint ASTM-ASME Committee on the Effects of Temperature on the Properties of Metal, was organized by the Test Methods Panel, J. J. Kanter, chairman. Much interest centers in defining the precision of temperature measurement and control which can be recommended or specified in high-temperature test work. The panel session was organized for the presentation and discussion of work in this field. Discussion leaders of the panel included William F. Roeser, U. S. Bureau of Standards, P. H. Dike, Leeds & Northrup Co., and J. R. Freeman, University of Michigan, together with the authors of the paper introducing the discussion:

Thermocouple "Immersion" Errors—J. M. Berry and D. L. Martin, presented by Mr Berry.

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[12] Issued as separate publication *ASTM STP No. 178.*

TWENTY-THIRD SESSION—FATIGUE

THURSDAY, JUNE 30, 9:30 A.M.

SESSION CHAIRMAN: G. R. GOHN

Behavior of Ti-75A Titanium Alloy Under Repeated Load—R. G. Crum and E. D'Appolonia, presented by Mr. Crum.

Strength, Damping, and Elasticity of Materials Under Increasing Reversed Stress with Reference to Accelerated Fatigue Testing—F. H. Vitovec and B. J. Lazan, presented by Mr. Lazan.

An Investigation of Strain Aging Effects in Fatigue—J. C. Levy and G. M. Sinclair, presented by Mr. Sinclair.

Understressing as a Means of Eliminating the Damaging Effect of Fatigue Stressing—Henry E. Frankel and J. A. Bennett, presented by Mr. Frankel.

(Continued in the Twenty-eighth and Thirty-second Sessions)

TWENTY-FOURTH SESSION—SYMPOSIUM ON METALLIC MATERIALS FOR SERVICE AT TEMPERATURES ABOVE 1600 F[13]

THURSDAY, JUNE 30, 2:00 P.M.

SESSION CHAIRMAN: V. N. KRIVOBOK
CO-CHAIRMEN: E. N. SKINNER
C. T. EVANS

Some Sheet and Bucket Materials for Jet Engine Application at 1600 F and Higher—J. P. Denny, L. P. Jahnke, E. S. Jones, and F. C. Robertshaw, presented by Mr. Robertshaw.

Influence of Boron on Cast Cobalt-Base S-816 Alloy—W. E. Blatz, E. E. Reynolds, and W. W. Dyrkacz, presented by Mr. Reynolds.

The Effect of Heat Treatment and Structure Upon Creep Properties of Nimonic Alloys Between 750 and 950 C—W. Betteridge and R. A. Smith, presented by Clarence Bieber.

Stress-Rupture Properties of Inconel 700 and Correlation on the Basis of Several Time-Temperature Parameters—S. S. Manson and G. Succop, presented by Mr. Manson.

Chromium-Nickel Alloys for High-Temperature Application—A. Bucklin and N. J. Grant, presented by Mr. Grant.

Effect of Rare Earth Additions on the High-Temperature Properties of a Cobalt-Base Alloy—J. E. Breen and J. R. Lane, presented by Mr. Breen.

Creep Rupture and Notch Sensitivity Properties of S-816 Alloy up to 1650 F Under Various Combinations of Fatigue and Static Stress—F. H. Vitovec and B. J. Lazan, presented by Mr. Lazan.

(Symposium Continued in the Twenty-seventh Session)

TWENTY-FIFTH SESSION—REPORT SESSION

THURSDAY, JUNE 30, 4:30 P.M.

SESSION CHAIRMAN: PAST-PRESIDENT T. S. FULLER

Committee B-7 on Light Metals and Alloys, Cast and Wrought:

Report presented by I. V. Williams, chairman, and the following actions taken:

Accepted as Tentative, Revisions in:

Spec. for Aluminum-Base Alloy Sand Castings (B 26 - 54 T)

Spec. for Magnesium-Base Alloy Sand Castings (B 80 - 54 T)

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[13] Issued as separate publication *ASTM STP No. 174.*

Spec. for Magnesium-Base Alloy Sheet (B 90 - 51 T)
Spec. for Magnesium-Base Alloy Forgings (B 91 - 54 T)
Spec. for Magnesium-Base Alloys in Ingot Form for Sand Castings, Die Castings, and Permanent Mold Castings (B 93 - 52 T)
Spec. for Magnesium-Base Alloy Bars, Rods, and Shapes (B 107 - 53 T)
Spec. for Aluminum-Base Alloy Permanent Mold Castings (B 108 - 54 T)
Spec. for Magnesium-Base Alloy Permanent Mold Castings (B 199 - 54 T)
Spec. for Magnesium-Base Alloy Extruded Round Tubes (B 217 - 53 T)

Adopted as Standard:

Spec. for Aluminum Bars for Electrical Purposes (Bus Bars) (B 236 - 52 T)
Rec. Practice for Codification of Light Metals and Alloys, Cast and Wrought (B 275 - 53 T)

The committee withdrew from the report as preprinted the recommendation for the adoption as standard of tentative specifications B 178 - 54 T, B 209 - 54 T, B 210 - 54 T, B 211 - 54 T, B 221 - 54 T, B 234 - 54 T, B 235 - 54 T, B 241 - 54 T, B 247 - 54 T, B 273 - 54 T, B 274 - 54 T.

Adopted as Standard, Revisions in:

Spec. for Magnesium Ingot and Stick for Remelting (B 92 - 52)
Spec. for Aluminum-Base Alloys in Ingot Form for Sand Castings, Die Castings, and Permanent Mold Castings (B 179 - 53)

Reapproval of Standards:

Spec. for Aluminum Ingots for Remelting (B 24 - 46)
Spec. for Aluminum for Use in Iron and Steel Manufacture (B 37 - 49)
Test for Dielectric Strength of Anodically Coated Aluminum (B 110 - 45)
Test for Sealing of Anodically Coated Aluminum (B 136 - 45)
Test for Weight of Coating on Anodically Coated Aluminum (B 137 - 45)

Paper Appended:

Mr. L. H. Adam was then called upon to present his paper on "Atmospheric Exposure of Wrought Aluminum and Magnesium Alloys," appearing as an appendix to the report.

Committee E-2 on Emission Spectroscopy:

Report presented by Cyrus Feldman, secretary, and accepted as a report of progress.

TWENTY-SIXTH SESSION—REPORT SESSION

THURSDAY, JUNE 30, 4:30 P.M.

SESSION CHAIRMAN: A. ALLAN BATES

Committee C-1 on Cement:

Report presented by R. R. Litehiser, chairman, and the following actions taken

Accepted as Tentative:

Spec. for Slag Cement (C 358 - 55 T)
Test for False Set of Portland Cement (C 359 - 55 T)

Accepted as Tentative, Revisions in:

Test for Air Content of Hydraulic Cement Mortar (C 185 - 53 T)
Spec. for Flow Table for Use in Tests of Hydraulic Cements (C 230 - 52 T)
Test for Bleeding of Cement Pastes and Mortars (C 243 - 53 T)
Test for Calcium Sulfate in Hydrated Portland Cement Mortar (C 265 - 54 T)
Method for Mechanical Mixing of Hydraulic Cement Mortars of Plastic Consistency (C 305 - 53 T)
Spec. for Portland-Pozzolan Cement (C 340 - 54 T)
Methods of Sampling Hydraulic Cement (C 183 - 46)

Adopted as Standard:

Test for Heat of Hydration of Portland Cement (C 186 - 54 T)
Def. of the Term Pozzolan (C 219 - 53 T): The committee recommended that Tentative Definition C 219 - 53 T be adopted as standard and incorporated in the Standard Definitions C 219 - 53, and the title changed to read Standard Definitions of Terms as Applied to Hydraulic Cement.

Adopted as Standard, Revisions in:

Spec. for Masonry Cement (C 91 - 53): Covering (1) adoption as standard of tentative revisions of Sections 3, 18, 19, 23, and 30(*a*); and (2) immediate adoption of revisions of Sections 19 and 30(*b*).

Test for Normal Consistency of Hydraulic Cement (C 187 - 49)
Test for Fineness of Portland Cement by Air Permeability Apparatus (C 204 - 51)
Spec. for Portland Cement (C 150 - 53)
Spec. for Air-Entraining Portland Cement (C 175 - 53)

The report as preprinted presented the recommendation that revisions in Specifications C 150 and C 175 be published as tentative. This was changed to have the revisions, with the exception of those in Specifications C 150 relating to tensile strength requirements, adopted immediately, subject to confirming letter ballot in the committee. The revisions relating to tensile strength were withdrawn.

Withdrawal of Tentative:

Test for Sodium Oxide and Potassium Oxide in Portland Cement by Flame Photometry (C 228 - 49 T): The committee has recommended that Method of Test C 228 - 49 T be incorporated in the Tentative Methods of Chemical Analysis of Portland Cement (C 114 - 51 T).

Reapproval of Standards:

Test for Fineness of Hydraulic Cement by the No. 200 Sieve (C 184 - 44)
Test for Specific Gravity of Hydraulic Cement (C 188 - 44)
Test for Soundness of Hydraulic Cement Over Boiling Water (Pat Test) (C 189 - 49)
Test for Tensile Strength of Hydraulic Cement Mortars (C 190 - 49)

Committee C-8 on Refractories:

Report presented in the absence of the chairman by L. C. Gilbert, and the following actions taken:

Accepted as Tentative, Revisions in:

Test for Modulus of Rupture of Castable Refractories (C 268 - 51 T)
Test for Permanent Linear Change on Firing of Castable Refractories (C 269 - 51 T), with the withdrawal of Section 8(*a*) from the report as preprinted.
Test for Pyrometric Cone Equivalent (P.C.E.) of Refractory Materials (C 24 - 46)
Def. of Terms Relating to Refractories (C 71 - 53)

Adopted as Standard:

Classification of Single- and Double-Screened Ground Refractory Material (C 316 - 53 T)

Adopted as Standard, Revisions in:

Def. of Terms Relating to Refractories (C 71 - 53)
Test for Cold Crushing Strength and Modulus of Rupture of Refractory Brick and Shapes (C 133 - 49)
Spec. for Fireclay-Base Castable Refractories for Boiler Furnaces and Incinerators (C 213 - 51)

Reapproval of Standards:

Classification for Insulating Fire Brick (C 155 - 47)
Test for Refractory Brick Under Load at High Temperatures (C 16 - 49)
Test for Sieve Analysis and Water Content of Refractory Materials (C 92 - 46)
Test for Warpage of Refractory Brick and Tile (C 154 - 41)
Test for Combined Drying and Firing Shrinkage of Fireclay Plastic Refractories (C 179 - 46)
Test for Panel Spalling Test for Fireclay Plastic Refractories (C 180 - 52)
Test for Workability Index of Fireclay Plastic Refractories (C 181 - 47)
Test for Bonding Strength of Air-Setting Refractory Mortar (Wet Type) (C 198 - 47)
Test for Refractoriness of Air-Setting Refractory Mortar (Wet Type) (C 199 - 47)

Committee C-16 on Thermal Insulating Materials:

Report presented in the absence of the chairman by L. C. Gilbert, and the following actions taken:

Accepted as Tentative:

Spec. for Molded Cork Pipe Insulation for Low Temperatures (C 339 - 55 T)

Accepted as Tentative, Revisions in:

Spec. for Mineral Wool Batt Insulation (Industrial Type) (C 262 - 51 T)
Spec. for Mineral Wool Felt Insulation (Industrial Type) (C 264 - 51 T)
Spec. for Structural Insulating Board Made from Vegetable Fibers (C 208 - 48)
Test for Flexural Strength of Preformed Block-Type Thermal Insulation (C 203 - 51)
Methods of Testing Structural Insulating Board Made from Vegetable Fibers (C 209 - 48)

Adopted as Standard:

Spec. for 85 per cent Magnesia Block-Type Thermal Insulation (C 319 - 53 T)
Spec. for 85 per cent Magnesia Molded-Type Thermal Insulation for Pipes (C 320 - 53 T)
Rec. Practice for Clearance of Preformed Thermal Pipe Insulation (C 312 - 53 T)

Reapproval of Standards:

Spec. for 85 per cent Magnesia Thermal Insulating Cement (C 193 - 48)
Spec. for Asbestos Thermal Insulating Cement (C 194 - 48)
Spec. for Expanded or Exfoliated Vermiculite Thermal Insulating Cement (C 196 - 48)
Spec. for Diatomaceous Silica Thermal Insulating Cement (C 197 - 48)
Method of Sampling and Mixing Thermal Insulating Cement (C 163 - 44)
Test for Thermal Conductivity of Materials by Means of the Guarded Hot Plate (C 177 - 45)

Committee C-17 on Asbestos-Cement Products:

Report presented in the absence of the chairman by L. C. Gilbert, and the following actions taken:

Adopted as Standard:

Spec. and Methods of Test for Flat Asbestos-Cement Sheets (C 220 - 53 T)
Spec. and Methods of Test for Corrugated Asbestos-Cement Sheets (C 221 - 53 T)
Spec. and Methods of Test for Asbestos-Cement Roofing Shingles (C 222 - 53 T)
Spec. and Methods of Test for Asbestos-Cement Siding Shingles and Clapboards (C 223 - 53 T)
Spec. for Asbestos-Cement Pressure Pipe (C 296 - 53 T)

Committee C-21 on Ceramic Whiteware and Similar Products:

Report presented in the absence of the chairman by L. C. Gilbert, and the following actions taken:

Accepted as Tentative:

Test for Linear Thermal Expansion of Fired Whiteware Products by the Dilatometer Method (C 372 - 55 T)
Test for Water Absorption, Bulk Density, Apparent Porosity, and Apparent Specific Gravity of Fired Porous Whiteware Products (C 373 - 55 T)
Test for Moisture Expansion of Fired Whiteware Products (C 370 - 55 T)
Test for Impact Resistance of Ceramic Tableware (C 368 - 55 T)
Test for Modulus of Rupture of Fired Cast or Extruded Whiteware Products (C 369 - 55 T)
Test for Sieve Analysis of Non-Plastic Pulverized Ceramic Materials (C 371 - 55 T)

Accepted as Tentative, Revisions in:

Test for Modulus of Rupture of Fired Dry-Pressed Whiteware Specimens at Normal Temperature (C 328 - 53 T)

Adopted as Standard:

Def. of Terms Relating to Ceramic Whiteware (C 242 - 54 T), with the exception of the terms "ball clay" and "calcine" which are to be continued as tentative.

Committee C-22 on Porcelain Enamel:

Report presented in the absence of the chairman by L. C. Gilbert, and the following actions taken:

Accepted as Tentative:

Test for Fusion Flow of Porcelain Enamel Frits—Flow-Button Method (C 374 - 55 T)
Classification of Water Used in Milling of Porcelain Enamel (C 375 - 55 T)

Accepted as Tentative, Revisions in:

Def. of Terms Relating to Porcelain Enamels (C 286 - 51 T)
Test for 45-deg Specular Gloss of Porcelain Enamels (C 346 - 54 T)

Adopted as Standard:

Test for Adherence of Porcelain Enamel and Ceramic Coatings to Sheet Metal (C 313 - 53 T)

Accepted for Publication as Information Only:

Test for Determining the Sag Resistance of Steel Sheets for Porcelain Enameling

Suggested Method:

Test for Set Characteristics of Porcelain Enamel Clays—Slump Method

Committee D-8 on Bituminous Waterproofing and Roofing Materials:

Report presented by H. R. Snoke, chairman, and the following actions taken:

Accepted as Tentative:

Test for Contact Compatability of Bituminous Materials (D 1370 - 55 T)

Accepted as Tentative, Revisions in:

Methods of Testing Bituminous Emulsions for

Use as Protective Coatings for Metal (D 1010 - 49 T)

Spec. for Asphalt Shingles Surfaced with Mineral Granules (D 225 - 54)

Spec. for Asphalt Roll Roofings Surfaced with Powdered Talc or Mica (D 224 - 54)

Spec. for Asphalt Siding Surfaced with Mineral Granules (D 699 - 54)

Spec. for Wide Selvage Asphalt Roll Roofing Surfaced with Mineral Granules (D 371 - 51). (This standard was reverted to tentative and in its revised form certain revisions were incorporated that had been accepted for publication as tentative in 1954. Erroneously these tentative revisions were also referred to in the preprinted report as being recommended for adoption as standard.)

Adopted as Standard:

Methods of Sampling Bituminous Materials (D 140 - 52 T) (Jointly with Committee D-4)

Adopted as Standard, Revisions in:

Methods of Testing Emulsified Asphalts (D 244 - 49) (This Standard is under joint jurisdiction with Committee D-4, which Committee approved this revision in 1954.)

Spec. for Asphalt Roll Roofing Surfaced with Powdered Talc or Mica (D 224 - 54)

Reapproval of Standards:

Spec. for Bituminous Grout for Use in Waterproofing Above Ground Level (D 170 - 41)

Spec. for Bituminous Grout for Use in Waterproofing Below Ground Level (D 171 - 41)

Spec. for Asphalt Mastic for Use in waterproofing (D 491 - 41)

Spec. for Woven Cotton Fabrics Saturated with Bituminous Substances for Use in Waterproofing (D 173 - 44)

Spec. for Asphalt-Saturated Roofing Felt for Use in Waterproofing and in Constructing Built-Up Roofs (D 226 - 47)

Spec. for Coal-Tar Saturated Roofing Felt for Use in Waterproofing and in Constructing Built-Up Roofs (D 227 - 47)

Spec. for Asphalt-Saturated Asbestos Felts for Use in Waterproofing and in Constructing Built-Up Roofs (D 250 - 47)

Spec. for Coal-Tar Pitch for Roofing, Dampproofing and Waterproofing (D 450 - 41)

Spec. for Coal-Tar Pitch for Steep Built-Up Roofs (D 654 - 49)

Spec. for Asphalt-Saturated and Coated Asbestos Felts for Use in Constructing Built-Up Roofs (D 655 - 47)

Spec. for Asphalt for Use in Constructing Built-Up Roof Coatings (D 312 - 44)

Spec. for Asphalt for Dampproofing and Waterproofing (D 449 - 49)

Spec. for Creosote for Priming Coat with Coal-Tar Pitch in Dampproofing and Waterproofing (D 43 - 41)

Spec. for Sieve Analysis of Granular Mineral Surfacing for Asphalt Roofing and Shingles (D 1001 - 51)

Spec. for Primer for Use with Asphalt in Dampproofing and Waterproofing (D 41 - 41)

Methods of Testing Films Deposited from Bituminous Emulsions (D 466 - 42)

Methods of Sampling and Testing Felted and Woven Fabrics Saturated with Bituminous Substances for Use in Waterproofing and Roofing (D 146 - 47)

Test for Steam Distillation of Bituminous Protective Coatings (D 255 - 28)

Tests for Coarse Particles in Mixtures of Asphalt and Mineral Matter (D 313 - 41)

Tests for Sieve Analysis of Granular Mineral Surfacing for Asphalt Roofing and Shingles (D 451 - 40)

Tests for Sieve Analysis of Nongranular Mineral Surfacing for Asphalt Roofing and Shingles (D 452 - 40)

Methods of Testing Bituminous Mastics, Grouts and Like Mixtures (D 147 - 41)

Volume Correction Table for Tar and Coal-Tar Pitch (D 633 - 44)

Committee D-18 on Soils for Engineering Purposes:

Report presented by K. B. Woods, vice-chairman, and the following actions taken:

Accepted as Tentative, Revisions in:

Spec. for Materials for Soil-Aggregate Subbase, Base, and Surface Courses (D 1241 - 52 T)

Reapproval of Standards:

Method of Preparing Soil Samples for Mechanical Analysis and Determination of Subgrade Soil Constants (D 421 - 39)

Test for Centrifuge Moisture Equivalent of Soils (D 425 - 39)

Test for Field Moisture Equivalent of Soils (D 426 - 39)

Test for Shrinkage Factors of Soils (D 427 - 39)

TWENTY-SEVENTH SESSION—SYMPOSIUM ON METALLIC MATERIALS FOR SERVICE AT TEMPERATURES ABOVE 1600 F[13]

(Symposium Continued from Twenty-fourth Session)

THURSDAY, JUNE 30, 8:00 P.M.

SESSION CO-CHAIRMEN: V. N. KRIVOBOK
A. W. F. GREEN

Titanium-Carbide Base Cermets for High-Temperature Service—K. Pfaffinger, H. Blumenthal and F. W. Glaser, presented by Mr. Blumenthal.

Titanium-Carbide Products Produced by Infiltration Technique—L. P. Skolnick and C. G. Goetzel, presented by Mr. Skolnick.

High-Temperature Properties of Molybdenum-Rich Alloy Compositions Made by Powder Metallurgy—W. L. Bruckart and R. I. Jaffee, presented by Mr. Bruckart.

Tension and Torsion Tests on Nimonic Alloys at High Temperatures—E. D. Ward and W. G. Tallis, presented by Clarence Bieber.

Thermal Fatigue Testing of Sheet Metal—H. E. Lardge and Joseph Lucas, presented by Mr. Lardge.

The Development of Zirconium-Rich Protective Coatings and Brazing Materials for Heat-Resisting Alloys—A. Blainey, presented by V. N. Krivobok.

Joint Committee on Effect of Temperature on the Properties of Metals:

Report presented in the absence of the chairman by N. L. Mochel, and accepted as a report of progress.

TWENTY-EIGHTH SESSION—FATIGUE

(Continued from Twenty-third Session)

FRIDAY, JULY 1, 9:30 A.M.

SESSION CHAIRMAN: H. J. GROVER

The Fatigue Properties of Some Titanium Alloys—A. W. Demmler, Jr., M. J. Sinnott, and L. Thomassen, presented by Mr. Demmler.

Torsion Prestrain and the Fatigue Life of RC-55 Titanium Alloy—J. G. Kaufman and E. D'Appolonia, presented by Mr. Kaufman.

The Fatigue Properties of Wrought Phosphor Bronze Alloys—G. R. Gohn, J. P. Guerard, and H. S. Freynik, presented by Mr. Gohn.[14]

Effect of Alloy Content on the Metallographic Changes Accompanying Fatigue—M. S. Hunter and W. G. Fricke, Jr., presented by Mr. Fricke.

Axial Stress Fatigue Strengths of Several Structural Aluminum Alloys—F. M. Howell and J. L. Miller, presented by Mr. Howell.

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[14] This paper represents the fatigue portion of a report on "The Mechanical Properties of Wrought Phosphor Bronze Alloys," by G. R. Gohn, J. P. Guerard, and H. S. Freynik, published as a separate publication *ASTM STP No. 183.*

(Continued in Thirty-second Session)

TWENTY-NINTH SESSION—EFFECT OF TEMPERATURE

FRIDAY, JULY 1, 9:30 A.M.

SESSION CHAIRMAN: VICE-PRESIDENT C. H. FELLOWS

Thermal Shock Testing of High-Temperature Metallic Materials—Thomas A. Hunter, presented by the author.[15]

Some Thermal and Mechanical Properties of Inconel to High Temperatures for Use in Aerodynamic Heating Research—William J. O'Sullivan, Jr., presented by the author.

The Compression Creep Properties of Several Metallic and Cermet Materials at High Temperature—L. A. Yerkovich and G. J. Guarnieri, presented by Mr. Yerkovich.

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[15] Published in *ASTM STP No. 174.*

Tension Testing Apparatus for the Temperature Range of −320 to −452 F—E. T. Wessel, presented by the author.[16]

An Axial Loading Creep Machine—M. H. Jones and W. F. Brown, Jr., presented by Mr. Brown.[17]

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[16] Published in the ASTM BULLETIN, No. 211, January, 1956, p. 40 (TP 12).

[17] Published in the ASTM BULLETIN, No. 211, January, 1956, p. 53 (TP 25).

THIRTIETH SESSION—REPORT SESSION

FRIDAY, JULY 1, 11:30 A.M.

SESSION CHAIRMAN: VICE-PRESIDENT R. A. SCHATZEL

Committee D-2 on Petroleum Products and Lubricants:

Report presented in the absence of the chairman by L. C. Beard, Jr., and the following actions taken:

Accepted as Tentative:

Test for Lubricating Qualities of Graphites (D 1367 - 55 T)
Test for Trace Concentrations of Tetraethyllead in Primary Reference Fuels (D 1368 - 55 T)

Accepted as Tentative, Revisions in:

Test for Sulfur in Petroleum Products by the Lamp-Gravimetric Method (D 90 - 50 T)
Test for Saponification Number of Petroleum Products by Color-Indicator Titration (D 94 - 52 T)
Test for Copper Corrosion by Petroleum Products (Copper Strip Test) (D 130 - 54 T)
Method of Sampling Petroleum and Petroleum Products (D 270 - 53 T)
Spec. for Gasoline (D 439 - 54 T)
Test for Distillation of Plant Spray Oils (D 447 - 52 T)
Test for Aniline Point and Mixed Aniline Point of Petroleum Products and Hydrocarbon Solvents (D 611 - 53 T)
Test for Oil Content of Petroleum Waxes (D 721 - 53 T)
Test for Neutralization Value (Acid and Base Numbers) by Color-Indicator Titration (D 974 - 54 T)
Test for Hydrogen in Petroleum Fractions by the Lamp Method (D 1018 - 49 T)
Test for Bromine Number of Petroleum Distillates (Color-Indicator Method) (D 1158 - 52 T)
Test for Bromine Number of Petroleum Distillates (Electrometric Method) (D 1159 - 52 T)
Methods of Calibrating Liquid Containers (D 1220 - 52 T)
Test for Sulfur in Petroleum Products and Liquefied Petroleum Gases by the CO_2-O_2 Lamp Method (D 1266 - 53 T)
Test for Hydrocarbon Types in Liquid Petroleum Products (Fluorescent Indicator Adsorption FIA Method) (D 1319 - 54 T)
Test for Olefinic Plus Aromatic Hydrocarbons in Petroleum Distillates (D 1019 - 51), with deletion of Appendix IV on Centrifuge on p. 101 of the preprinted report.

Standard Reverted to Tentative Without Revision:

Test for Dilution of Crankcase Oils (D 322 - 35)

Adopted as Standard:

Test for Aromatic Hydrocarbons in Olefin-Free Gasolines by Silica Gel Adsorption (D 936 - 51 T)
Test for Oxygen in Butadiene Vapors (Manganous Hydroxide Method) (D 1021 - 53 T)
Test for Effect of Grease on Copper (D 1261 - 53 T)
Test for Lead in New and Used Greases (D 1262 - 53 T)
Method of Sampling Liquefied Petroleum Gases (D 1265 - 53 T) (Jointly with Committee D-3)
Test for Unsaturated Light Hydrocarbons (Silver-Mercuric Nitrate Method) (D 1268 - 53 T)

Adopted as Standard, Revisions in:

Test for Measurement of Freezing Points for Evaluation of Purity (D 1015 - 49 T)
Test for Determination of Purity from Freezing Points (D 1016 - 54 T)
Test for Vapor Pressure of Liquefied Petroleum Gases (D 1267 - 53 T)
Test for API Gravity of Petroleum and Its Products (Hydrometer Method) (D 287 - 54)
Test for Vapor Pressure of Petroleum Products (Reid Method) (D 323 - 52)

Test for Oxidation Stability of Gasoline (Induction Period Method) (D 525 - 49)
Test for Sulfated Residue from New Lubricating Oils (D 874 - 51)
Test for Knock Characteristics of Motor Fuel by the Research Method (D 908 - 53)
Test for Density of Hydrocarbon Liquids by the Pycnometer (D 941 - 49)
Test for Apparent Viscosity of Lubricating Greases (D 1092 - 51)
ASTM-IP Petroleum Measurement Tables (D 1250 - 53), comprising extensions of Tables 6 and 7 from 0 to −50 F, and new Table 34 for LPG to replace Table 32, subject to joint approval by Institute of Petroleum (London).
Test for Specific Gravity of Petroleum and Its Products (Hydrometer Method) (D 1208 - 54)

Accepted for Publication as Information Only:

Test for Emulsion Stability of Soluble Cutting Oils
Test for Galvanic Corrosion Associated with Instrument Lubricating Oils
Test for Blocking Point of Paraffin Wax
Test for Oxidation Stability of Paraffin Wax (Peroxide Method)
Test for Vanadium in Residual Fuel Oil
Test for Estimation of Heat of Combustion of Liquid Petroleum Products
Test for Tetraethyllead in Gasoline by Direct-Reading Polarograph
Test for Consistency of Semifluid Greases
Test for Estimation of Deleterious Particles in Lubricating Grease
Test for Benzene, Toluene, Ethylbenzene, and Individual Xylenes by Infrared Spectrophotometry
Test for Measuring the Color of Petroleum Products (ASTM Color Scale), as a contemplated revision of Method D 155.
Test for Water in Bituminous Materials, as a contemplated revision of Method D 95.

The committee withdrew from the report as preprinted the recommendation for the withdrawal of the Tentative Method of Test for Steam Emulsion of Lubricating Oils (D 157 - 51 T).

Committee D-3 on Gaseous Fuels:

Report presented in the absence of the chairman by P. J. Smith, and the following actions taken:

Adopted as Standard:

Methods for Measurement of Gaseous Fuel Samples (D 1071 - 54 T)
Method of Sampling Liquefied Petroleum Gases (D 1265 - 53 T) (Jointly with Committee D-2)

Adopted as Standard, Revisions in:

Test for Calorific Value of Gaseous Fuels by the Water-Flow Calorimeter (D 900 - 48)

Committee D-4 on Road and Paving Materials

Report presented by K. B. Woods, vice-chairman, and the following actions taken:

Accepted as Tentative:

Rec. Practice for Quantities of Materials for Bituminous Surface Treatments (D 1369 - 55 T)

Accepted as Tentative, Revisions in:

Test for Compressive Strength of Bituminous Mixtures (D 1074 - 52 T)
Spec. for Crushed Stone, Crushed Slag, and Gravel for Single, Double or Multiple Bituminous Surface Treatments (D 1139 - 52 T). In the preprinted report, this revised specification was inadvertently listed under the heading of New Tentatives.
Spec. for Mineral Filler for Sheet Asphalt and Bituminous Concrete Pavements (D 242 - 39)
Test for Distillation of Tars and Tar Products (D 20 - 52)

Adopted as Standard:

Spec. for Hot-Mixed, Hot-Laid Asphaltic Concrete for Base and Surface Courses (D 947 - 54 T)
Methods of Sampling Bituminous Materials (D 140 - 52 T)

Adoption as Standard, Revisions in:

Def. of Terms Relating to Materials for Roads and Pavements (D 8 - 52)
Method of Test for Distillation of Tars and Tar Products (D 20 - 52)
Test for Distillation of Cut-Back Asphaltic Products (D 402 - 49)
Spec. for Crushed Stone, Crushed Slag, and Gravel for Water-Bound Macadam Base and Surface Courses of Pavements (D 694 - 49)
Spec. for Bituminous Mixing Plant Requirements (D 995 - 53)
Test for Sieve Analysis of Mineral Filler (D 546 - 41)

Test for Abrasion of Coarse Aggregate by Use of the Los Angeles Machine (C 131 - 51) (Jointly with Committee C-9)
Test for Abrasion of Graded Coarse Aggregate by Use of the Deval Machine (D 289 - 53) (Jointly with Committee C-9)

Reapproval of Standards:

Test for Amount of Material Finer than No. 200 Sieve in Aggregates (C 117 - 49) (Jointly with Committee C-9)
Test for Sieve Analysis of Fine and Coarse Aggregates (C 136 - 46) (Jointly with Committee C-9)
Test for Specific Gravity and Absorption of Coarse Aggregate (C 127 - 42) (Jointly with Committee C-9)
Test for Specific Gravity and Absorption of Fine Aggregate (C 128 - 42) (Jointly with Committee C-9)
Method of Sampling Stone, Slag, Gravel, Sand, and Stone Block for Use as Highway Materials (D 75 - 48)

Committee D-6 on Paper and Paper Products:

Report presented in the absence of the chairman by S. F. Etris, and the following actions taken:

Accepted as Tentative, Revisions in:

Fiber Analysis of Paper and Paperboard (D 1030 - 49 T)
Test for Resistance of Paper to Passage of Air (D 726 - 48)
Test for Water Resistance of Paper, Paperboard, and Other Sheet Materials by the Dry-Indicator Method (D 779 - 54)

Adopted as Standard:

Test for Moisture in Paper, Paperboard, and Paperboard and Fiberboard Containers (D 644 - 53 T)

Adopted as Standard, Revisions in:

Test for Wire and Felt Sides of Paper (D 725 - 45)

Reapproval of Standards:

Test for Ash Content of Paper and Paper Products (D 586 - 42)
Test for Casein in Paper (Qualitative) (D 587 - 42)
Test for Alpha-, Beta-, and Gamma-Cellulose in Paper (D 588 - 42)
Test for Paraffin Content of Waxed Paper (D 590 - 42)
Test for Adhesiveness of Gummed Tape (D 773 - 47)
Test for Absorption by Bibulous Papers of Water and Writing Ink (D 824 - 47)
Test for Degree of Wet Curl of Paper (D 826 - 47)
Test for Bleeding Resistance of Asphalted Paper at Elevated Temperature (D 917 - 49)
Test for Copper Number of Paper and Paperboard (D 919 - 49)
Test for Crease Retention of Wrapping Paper (D 920 - 49)

The committee withdrew from the report as preprinted the recommendation for the reapproval of Standard Methods D 528 - 41, D 643 - 43, and D 827 - 47.

Committee D-10 on Shipping Containers:

Report presented in the absence of the chairman by S. F. Etris, and the following action taken:

Accepted as Tentative:

Methods of Testing Package Cushioning Materials (D 1372 - 55 T)

Committee D-11 on Rubber and Rubber-like Materials:

Report presented by Simon Collier, chairman, and the following actions taken:

Accepted as Tentative:

Spec. for Ozone-Resistant Rubber Insulating Tape (D 1373 - 55 T)

Accepted as Tentative, Revisions in:

Methods of Sample Preparation for Physical Testing of Rubber Products (D 15 - 54 T)
Test for Adhesion of Vulcanized Rubber to Metal (D 429 - 47 T)
Test for Change in Properties of Elastomeric Vulcanizates Resulting from Immersion in Liquids (D 471 - 54 T)
Methods of Testing Hard Rubber Products (D 530 - 50 T)
Methods of Testing Automotive Air Brake and Vacuum Brake Hose (D 622 - 54 T)
Test for Resistance to Accelerated Light Aging of Rubber Compounds (D 750 - 43 T), with a further revision comprising the addition of a Note which is subject to letter ballot approval of Committee D-11.

Adopted as Standard:

Rec. Practice for Classifying Elastomeric

Compositions for Resilient Automotive Mountings (D 1207 - 52 T)

Test for Compression Set of Vulcanized Rubber (D 395 - 53 T)

Test for Physical State of Cure of Vulcanized Rubber (T-50 Test) (D 599 - 40 T)

Test for Permeability of Vulcanized Rubber or Synthetic Elastomers to Volatile Liquids (D 814 - 46 T)

Method of Testing Rubber Cements (D 816 - 51 T)

Test for Contact Migration Stain of Vulcanized Rubber in Contact with Organic Finishes (D 925 - 51 T)

Test for Mechanical Properties of Elastomeric Vulcanizates Under Compressive or Shear Strains by the Mechanical Oscillograph (D 945 - 52 T)

Test for Resistance of Vulcanized Rubber or Synthetic Elastomers to Cut Growth by the Use of the Ross Flexing Machine (D 1052 - 52 T)

Test for Impact Resilience and Penetration of Rubber by the Rebound Pendulum (D 1054 - 53 T)

Test for Discoloration of Vulcanized Rubber: Organic Finish Coated or Light Colored (D 1148 - 51 T)

Test for Weather Resistance Exposure of Automotive Rubber Compounds (D 1171 - 51 T)

Test for Low-Temperature Compression Set of Vulcanized Elastomers (D 1229 - 52 T)

Special permission was obtained from the Executive Committee of the Board of Directors to add a recommendation for the adoption as standard of the Tentative Methods of Testing Automotive Hydraulic Brake Hose (D 571 - 52 T), subject to letter ballot approval by Committee D-11.

The committee withdrew from the report as preprinted recommendations for the adoption as standard of Specifications D 735 - 54 T, Methods D 314 - 52 T, D 749 - 43 T, D 926 - 47 T, D 1149 - 51 T, and D 1206 - 52 T.

Reapproval of Standards:

Spec. for Rubber Matting for Use Around Electric Apparatus (Voltage Rating of Matting, 3000 volts) (D 178 - 24)

Spec. for Cotton Rubber-Lined Fire Hose for Public and Private Fire Department Use (D 296 - 49)

Test for Abrasion Resistance of Rubber Compounds (D 394 - 47)

Test for Adhesion of Vulcanized Rubber (D 413 - 39)

Test for Resistance to Light Checking and Cracking of Rubber Compounds (D 518 - 44)

Test for Indentation of Rubber by Means of the Pusey and Jones Plastometer (D 531 - 49)

Test for Viscosity and Total Solids Content of Rubber Cements (D 553 - 42)

Test for Compression-Deflection Characteristics of Vulcanized Rubber (D 575 - 46)

Test for Young's Modulus in Flexure of Natural and Synthetic Elastomers at Normal and Subnormal Temperatures (D 797 - 46)

Test for Hydrogen Permeability of Rubber-Coated Fabrics (D 815 - 47)

Committee D-15 on Engine Antifreezes:

Report presented by H. R. Wolf, chairman, and the following action taken:

Accepted as Tentative:

Method for Glassware Corrosion Test for Engine Antifreezes (D 1384 - 55 T)

Committee D-20 on Plastics:

Report presented by F. W. Reinhart, vice-chairman, and the following actions taken:

Accepted as Tentative, Revisions in:

Spec. for Phenolic Molding Compounds (D 700 - 54 T) (Jointly with Committee D-9)

Spec. for Laminated Thermosetting Materials (D 709 - 52 T) (Jointly with Committee D-9)

Spec. for Melamine-Formaldehyde Molding Compounds (D 704 - 51 T)

Spec. for Cellulose Acetate Molding Compounds (D 706 - 51 T)

Spec. for Cellulose Acetate Butyrate Molding Compounds (D 707 - 51 T)

Test for Measuring the Molding Index of Thermosetting Molding Compounds (D 731 - 54 T)

Test for Brittleness Temperature of Plastics and Elastomers by Impact (D 746 - 54 T)

Methods of Sampling and Testing Plasticizers Used in Plastics (D 1045 - 49 T)

Nomenclature of Descriptive Terms Pertaining to Plastics (D 675 - 54 T)

Def. of Terms Relating to Plastics (D 883 - 54 T). The committee withdrew from the report as preprinted the recommendation for the addition of definitions for "Extrusion" and "Molding, Compression."

Test for Acetyl and Butyryl Content of Cellulose Acetate Butyrate (D 817 - 49) (Jointly with Committee D-23)

Adopted as Standard:

Spec. for Ethyl Cellulose Molding Compounds (D 787 - 52 T)

Test for Volatile Loss from Plastic Materials (D 1203 - 52 T)
Test for Resistance of Plastic Films to Extraction by Chemicals (D 1239 - 52 T)
Test for Shrinkage of Molded and Laminated Thermosetting Plastics at Elevated Temperature (D 1299 - 53 T)
Test for Total Chlorine in Vinyl Chloride Polymers and Copolymers (D 1303 - 53 T)
Recommended Code for Designating Form of Material and Direction of Testing Plastics (D 1009 - 49 T)

The committee withdrew from the report as preprinted the recommendation for the adoption as standard of Methods D 542 - 52 T.

Adopted as Standard, Revisions in:

Spec. for Urea-Formaldehyde Molding Compounds (D 705 - 49)

Reapproval of Standards:

Test for Mar Resistance of Plastics (D 673 - 44)
Test for Shear Strength of Plastics (D 732 - 46)
Test for Impact Resistance of Plastics at Subnormal and Supernormal Temperatures (D 758 - 48)
Test for Tensile and Compressive Properties of Plastics at Subnormal and Supernormal Temperatures (D 759 - 48)
Rec. Practice for Determining Permanent Effect of Heat on Plastics (D 794 - 49)

The committee withdrew from the report as preprinted the recommendation for the reapproval of Method of Test for Colorfastness of Plastics to Light (D 620 - 49) and Recommended Practice for Accelerated Weathering of Plastics Using S-1 Bulb and Fog Chamber (D 795 - 49).

THIRTY-FIRST SESSION—REPORT SESSION

FRIDAY, JULY 1, 11:30 A.M.

SESSION CHAIRMAN: R. C. ALDEN

Committee A-3 on Cast Iron:

Report presented by H. W. Stuart, chairman, and the following actions taken:

Accepted as Tentative, Revisions in:

Spec. for Foundry Pig Iron (A 43 - 49 T)
Spec. for Chilled and White Iron Castings (A 360 - 52 T)
Methods of Chill Testing of Cast Iron (A 367 - 53 T)

Adopted as Standard:

Spec. for Automotive Gray Iron Castings (A 159 - 53 T)
Spec. for Nodular Iron Castings (A 339 - 51 T)

Reapproval of Standards:

Spec. for Cast Iron Soil Pipe and Fittings (A 74 - 42)
Spec. for Gray Iron Castings for Valves, Flanges, and Pipe Fittings (A 126 - 42)
Spec. for Cast Iron Culvert Pipe (A 142 - 38)
Methods of Compression Testing of Cast Iron (A 256 - 46)
Methods of Impact Testing of Cast Iron (A 327 - 54)
Rec. Practice for Evaluating the Microstructure of Graphite in Gray Iron (A 247 - 47)
Rec. Practice for Torsion Tests of Cast Iron (A 260 - 47)

Committee C-7 on Lime:

Report presented in the absence of the chairman by L. C. Gilbert, and the following actions taken:

Adopted as Standard, Revisions in:

Spec. for Hydraulic Hydrated Lime for Structural Purposes (C 141 - 42)

Reapproval of Standards:

Spec. for Quicklime and Hydrated Lime for Cooking of Rags in Paper Manufacture (C 45 - 25)
Spec. for Quicklime for Sulfite Pulp Manufacture (C 46 - 27)
Spec. for Hydrated Lime for Varnish Manufacture (C 47 - 27)
Spec. for Quicklime and Hydrated Lime for Silica Brick Manufacture (C 49 - 42)

Committee C-15 on Manufactured Masonry Units:

Report presented by J. W. Whittemore, chairman, and the following actions taken:

Accepted as Tentative, Revisions in:

Spec. for Structural Clay Load-Bearing Wall Tile (C 34 - 52)
Spec. for Structural Clay Non-Load-Bearing Tile (C 56 - 52)
Spec. for Structural Clay Floor Tile (C 57 - 52)

Adopted as Standard:

Spec. for Drain Tile (C 4 - 54 T)

Adopted as Standard, Revisions in:

Spec. for Structural Clay Load-Bearing Wall Tile (C 34 - 52)
Spec. for Vitrified Clay Filter Block for Trickling Filters (C 159 - 51)
Def. of Terms Relating to Structural Clay Tile (C 43 - 50)
Spec. for Concrete Building Brick (C 55 - 52)
Methods of Sampling and Testing Concrete Masonry Units (C 140 - 52)

Reapproval of Standard:

Spec. for Paving Brick (C 7 - 42)

Committee D-22 on Methods of Atmospheric Sampling and Analysis:

Report presented in the absence of the chairman by F. Y. Speight, and accepted as a report of progress.

THIRTY-SECOND SESSION—SESSION ON FATIGUE

(*Continued from Twenty-third and Twenty-eighth Sessions*)

FRIDAY, JULY 1, 1:30 P.M.

SESSION CHAIRMAN: D. G. RICHARDS

The Effect of Size and Shape of the Specimen, Shape of the Notch and Grain Size of the Metal on the Fatigue Strength of Smooth and Notched Specimens in Medium Carbon Steel—Ch. Massonnet, presented by title only.
Anisotropy of Fatigue Strength in Bending and in Torsion of a Steel and Two Aluminum Alloys—W. N. Findley and P. N. Mathur, presented by Mr. Mathur.
The Behavior of Long Helical Springs Under Fluctuating Load—C. L. Staugaitis and H. C. Burnett, presented by Mr. Staugaitis.
The Effect of an Anodic (HAE) Coating on the Fatigue Strength of Magnesium Alloy Specimens—J. A. Bennett, presented by the author.
Statistical Estimation of the Endurance Limit—E. J. Gumbel, presented by title only.

Committee E-9 on Fatigue:

Report presented by R. E. Peterson, chairman, and accepted as a report of progress.

EDITORS' NOTE.—The recommendations affecting standards and the Amendments to the By-laws referred to letter ballot were approved when the ballot was canvassed on September 12.

WHAT IS IT?

Annual Address by the President

Norman L. Mochel[1]

June 28, 1955

In recent years, I am sure that you have noted a tendency on the part of our retiring President to let the report of the Board of Directors speak for the activities and well-being of the Society, and to use the time allotted to him to deal with a subject that seemingly impressed him, beyond the ordinary, during the year.

Two years ago Dr. Maxwell spoke of "People and Things," of the manner in which we pay tribute to the dignity and well-being of people, and to the usefulness of things. People, he reminded us, are infinitely more important than things.

And last year, at that very colorful luncheon meeting at Chicago, Dr. Beard spoke of "Plain Talk." He desired to discuss what he called an unhealthy trend in science—the breaking down of communications between the various sciences and the public. He spoke for the opportunity of better identification and understanding of people and things, through the medium of plain talking.

The now retiring President would follow this trend of recent years. Indeed, he sincerely hopes that his remarks of the hour may well fit, as it were, in a series with those of Dr. Maxwell and Dr. Beard, since he, too, is interested in people and things, and for better communications—and better identifications.

Better Identification

At this point, I am reminded of that incident in William Shakespeare's great comedy *As You Like It,* where the rather likable Jaques, in exile in the forest with the deposed Duke, has an encounter with Touchstone, the jester. Upon meeting with the Duke later at dinner, he tells the assembled company:

> "A fool, a fool! I met a fool i' the forest,
> A motley fool;"

and after describing the encounter in some detail, he ended with:

> "O that I were a fool!
> I am ambitious for a motley coat."

Upon being told by the Duke that he might have one, Jaques then reminded his friends that:

> "I must have liberty
> Withal, as large a charter as the wind,
> To blow on whom I please; for so fools have;
> And they that are most galled with my folly,
> They most must laugh."

During this past year, and especially in one instance, and purely because I was your President, and because of our deeds or lack of deeds as a Society, I was subjected to what I may honestly call severe criticism and pressure. You will all recall, from the rather wide newspaper coverage, of a serious mishap that occurred during the dock trials of our first atomic-powered submarine, the *Nautilus*, in that a steam pipe burst under pressure, with injury to operating personnel, and serious delay in putting the *Nautilus* to sea. It developed, as all who read must know, that the failed pipe was not of proper grade. The piping had been ordered to an ASTM specification, and immediately the specification, the several revisions that had been made to it, and the entire question of marking and ready identification were a fit subject for critical examination.

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[1] **Manager, Metallurgical Engineering, Westinghouse Electric Corp., Philadelphia, Pa.**

During the Western trip in February and March of the President and the Executive Secretary, they were at dinner with a group of ASTM members and their wives, at a place that shall be nameless, in San Francisco. To keep us busy while the food was being prepared, the long table was generously provided with platters of two articles of food. It was obvious that the well-browned and tasty bones that were given us to gnaw upon are usually referred to as spare-ribs. The other article was a triangular-shaped pastry of some sort. Soon the question developed at my end of the table as to what it was. Having known from my boyhood days something of the manner in which pie and pastry makers mark their product, I carefully looked for an "S" for "snake" or "shark," or an "O" for "octopus," or the like, but there were none such marks. On opposite sides of the table were two chemical engineers of wide experience. Each took a piece of the questionable article. Said one to the other, "Let us, two chemists of world-wide reputation, taste and see if we cannot tell what it is . . ." But after tasting, both shook their heads and both were heard to say "What is it?"

Of course, the point in this little incident, aside from giving me my title, is that maybe it is well that some things are not and cannot be too well identified.

The pastry also leads me to the point that from our very earliest childhood, we are taught to identify things and ourselves:

"Patty cake, patty cake, baker's man,
Bake me a cake, as fast as you can,
Pat it, and roll it, and mark it with 'T,'
And put it in the oven for Tommy and
me."

Possession or potential possession has long been a basis for marking. One of our very early markings for identification was a symbol of the British Crown, in the form of a broad arrow, which marked the larger pine trees in New Hampshire and Maine that were set aside for the Crown, to be used as masts on sailing ships. Way back in the valleys, every once in a while they run across one of these markings even today.

The identification of people down through the ages, even to now, is an interesting subject. From the very beginning, when we are told that God put a mark on Cain, the military, church, state, society, and industry have, for various reasons, identified people by dress, badge, symbol, hair, and even by branding.

Look around this room. We are all sedately identified. Why? Much of it is lost—but it is important to us that the 1 or 5 or 10 or 50 or even 99 per cent who do not know us—may see who we are.

Many of you belong to those organizations where upon entering the room you go to a rack and get your large round badge, with perhaps RED in great big letters and Smith in small letters, or SLIM in great big letters and Brown in small letters; otherwise no one would know that you treasure the memory that once the hair was of Titian-blond or the figure less robust.

Now identification of both people and

things becomes more important and there is greater responsibility, as our knowledge of people and things grows. I have in my hand one of the "dog-tags" that I wore on a greasy tape around my neck in World War I. Just my name, and USA, and my serial number. I also hold one more recently worn by my younger son. The name, the USA, the serial number are there. But now there is the date of the tetanus shots, the type of blood, and down in the corner, a *P*, a *C*, or a *J*, to show his religion. It is important that these things be there with the person, for immediate use, rather than to be recorded only on the man's service record which may be miles away, or not at all. And this is true for materials at times.

Identification markings or methods will vary in many ways, depending upon the nature of the person or thing. To identify or not to identify is the first question. It is easy to identify some things; it is very difficult to identify others. But the difficulty of doing it must not be accepted as the reason for not doing it. The matter of cost will also vary and here comes in a matter of values. Indeed it would appear that in some cases, where necessity hardly applies, great lengths are gone to in identification; but in others, where property loss and very life are involved, we worry as to costs and difficulties.

PERMANENCE—A PROBLEM

Permanence of identification is often a problem. The purpose has a time value. The identification of a can of tomatoes is of little use after the can is opened and the contents consumed. When specification changes are made that are of any moment, changed identifications must be employed. Yes, there are problems, even here. I am sure you all heard of the big American sailor who returned to the tattoo artist to see if the name Gwendolyn on a hairy chest could not in some way be changed to Mary.

IDENTIFICATION MUST BE REAL

Identification must be real, truthful, not fictitious. I recall many years ago being in the shipping room of a steel mill—now closed down, so the tale may be told. To my utter amazement I saw stacks of tool steel labels, of two if not three other branch plants located in other parts of the country, and of Standard, Choice, and Special grades, all being pasted on bars from the same racks, to suit various orders. And to my question, you will be amazed at the answer: "We give him the color label and the name that he wants." That day I trust is gone forever.

Identification, just as Dr. Beard said about talk, must communicate properly. A story will illustrate, I am sure.

A customer in a Montreal restaurant went to the washroom, turned on a cold tap and just escaped being badly scalded.

"This is an outrage!" he screamed at the manager. "Why aren't your taps marked properly?"

The manager led the injured diner back to the washroom. "Look," he said patiently. "The tap is marked 'C' correctly. That stands for 'chaude,' and in French 'chaude' means 'hot!' You should know that if you live in Montreal."

The customer stood abashed for a moment. Then he made a discovery. "But look again," he cried. "The other tap is marked with a 'C' also! What about that?"

"Ah," said the proprietor, "that stands for 'cold.' This is a bilingual restaurant, my friend."

EXAMPLES—MILITARY; FIBERS; PRESSURE VESSELS; METAL PRODUCTS; DRUGS

The identification of pipe lines and compressed gas cylinders has long been an important matter. There have been serious disfigurements and even deaths from errors from poor identification of both. Military Standard 101A was issued last year. An excellently stated Foreword to the specification ends in this manner: "While this standard was prepared for use by the Military Establishments, it is the hope that industry as a whole will eventually adopt this color code." I recently called to the attention of the operating head of a new and large engineering laboratory that there was such a specification and, knowing that he would have a growing problem of identification of both piping and gas cylinders, suggested that he consider its adoption. Upon being told that his piping problem was too complicated, if anything, the very reason for the adoption of the specification, I must confess I gave up.

One reads with much interest of the many synthetic fibers on the market or ready to go on the market, or still in the pilot plant or test tube stage. One appreciates the tremendous testing program under way today, as you and I carry out this program by buying and wearing the product application of these fibers. Take a good look, as textile experts say, at the label on any new blended fabric and make sure it states the exact percentages of each fiber. They say that this will not mean much to you; to this I would disagree in part, since you and I will report the actual results in the old law of demand, but they point out that a responsible manufacturer will not hesitate to say just what his material contains.

I have already made reference to the Military Specification for identifying pipe lines and gas cylinders. Work is progressing along military and national lines and in other fields as well. For example, a specification covering the identification of iron and steel products in general has had wide attention. As another example, one dealing with the Nylon Cord Manufacturers Color Code Identification is worthy of reference in the aviation field. I think we are all familiar with excellent identification practices on the part of the fire underwriters, on electrical parts and on boilers and heat exchangers. The identification system devised by the National Electrical Manufacturers Assn. for welding electrodes is an important matter, worthy of note. And even such things as chocolate candy have identification practices.

Private companies have effected identification systems based on colors for their product. It is noted that the Aluminum Company of America has a color system for distributors' stocks of aluminum and its alloys. Other nationwide distributors of metal products have color standards. And nearly every consuming interest has an internal color standard. But the same color means something widely different from place to place, and this means trouble some place, sometime, for someone.

I hold in my hand a metal container, full of white pills, of a well-known article, which after these rambling words, I may have to use this afternoon. If I lose these particular pills from this container, I shall still know what they are, for each pill is double marked. It gives me confidence. I have a good friend who operates a very high-grade apothecary establishment. I was interested to know how far the manufacturers of drugs had gone in identification on the pills as well as on the package. By printing, forming, indenting, speckling, full and partial colors, as well as size and shape, I found tremendous strides are being made in this field of which I know very little. Yet, I picked up, just for example, eight different white pills about the size of those in my container. They are entirely different. They range from common sodium bicarbonate to several rather potent drugs. I mix them, and I am lost. The containers are very pretty, I shall save them. The eight white pills must go down the drain.

PIPE AND ITS PROBLEM

Now it's a far cry from pills to pipe. They have common letters *p* and *i*—they're usually round. But here the similarity ends. Yet we have a similar problem. Here are three peices of steel pipe, all of the same diameter and wall thickness. One is butt-welded pipe for very ordinary service; the second is of seamless carbon steel for higher grade services; the third an alloy steel for high-pressure service at red heat. At this stage, they have lost their identity. Some here who are experts might pick out the poorest grade. Most of you could not. Misapplication may bring death, injury, and loss of property. And yet we allow the identification of smaller sizes of these pipes—and do not even define what are "smaller sizes"—by tying in a bundle and tying a metal tag to the bundle. And the statement has been made that it is just a matter of good housekeeping to keep these various grades of pipe properly identified and safely applied at all times. And here's a piece of stainless steel tubing for use at higher temperatures and pressures. A little bit of alloy addition allows its use at far higher stresses at these red heats than similar steel without the additional alloy. And with no marking provided and absolutely no difference in appearance, we expect good housekeeping to keep us safe from harm. I am told that a marine boiler recently taken from a ship contained everything from plain carbon steel to 4 per cent chromium steel, mixed "willy-nilly" throughout. Good housekeeping! I wonder how the ladies would feel in our large grocery stores that keep getting larger and larger, if all the canned goods were identified only by the crates they came in. Even this is better than the tied bundles of pipe. And imagine our shelves in the stores filled with bare cans, and you ladies were dependent only on good housekeeping at the stores, and in your own storage, as to whether the can contained corn or peaches, or what not. I'm sure you ladies just would not put up with such a situation and would demand better identification.

ASTM STANDARDS—MORE MARKING?

I have made no attempt to read all of the specifications in our seven volumes of standards. But I did make spot checks in all fields, and I am convinced that, as a Society creating specifications for engineering materials, we have left much undone in our work. In many cases, we require only that the name of the manufacturer shall appear. So often we do not require marking to show that the material meets our own ASTM specification, and that's not very good advertising! I watched the unloading of a truck load of bags of cement the other day. Some bags were prominently marked as meeting such and such grade of an ASTM specification. But a large part of the lot was not marked. Was this a grade too poor to be marked? I looked into it and found that we do not require that the lowest grade in the specifications be marked. Advertising is a good way to communicate to the public. I look at every load of ready-mixed concrete that passes me on the street, and the day I see one with a large sign on it that the product in this truck meets an ASTM specification, I'll doff my hat and say "Well done," or "Amen."

Everywhere I go, I see products that *were made* or *should have been made* to ASTM specifications. And there are many important applications where it appears to me that identification to the specifications should be there for *all* to see. In my opinion, we have done well in our identification requirements in many; we have done average in many; we have done poorly in others. It's a little like my friend Touchstone, the jester of *As You Like It*, who said when he received the answer "So so" to a question. His remark was:

> "So so is good, very good, very excellent
> good;
> And yet it is not, it is just so so."

And I think we should stop being just "So so."

And then there are new fields ahead. We have a new subcommittee on hydraulic lubricants. Recently several of us were visiting at a plant where a turbine was operating on a synthetic lubricant. One of our number innocently did what any engineer would do—stuck his hand in an exposed flow to "feel" the oil. Quickly, without a word he was unceremoniously rushed to a washroom and washed free of the liquid. Whether the matter was real or for effect, I do not know. Another friend instinctively picked up a mechanical part that had been in service where nuclear products were involved. He was rushed to a decontamination center forthwith. These are merely referred to as evidence of the more complex things ahead.

It follows that as life becomes more complicated, as the atomic age comes in, and more dangers are present, if we are to really believe as Dr. Maxwell said that people are infinitely more important than things, then for self protection people will have to pay more attention to this matter of identification.

In conclusion, I ask myself and you three questions:

1. Will we take this matter seriously and solve those problems before us?

2. Or will we wait until the public takes it in hand and by legislation takes over?

3. Must we perfect and further develop test apparatus and methods that will permit checking of materials in final place—before actual operation?

I close with a suggested slogan:

"He who creates shall identify."

ANNUAL REPORT OF THE BOARD OF DIRECTORS

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As this report is being prepared, the business reports from industry indicate a period of great activity and progress. It would be expected that the Society which is so admirably supported by industry, and whose working committees comprise the leading technical representatives in the materials field of industry,

HIGH LIGHTS, 1954 FINANCIAL OPERATIONS

	1954	1953	1952
Gross Receipts:			
Membership Dues	$236 400	$233 700	$226 300
Sales of Publications	470 500	512 300	338 500
Other	87 700	68 600	83 600
Total	794 600	814 600	648 400
Expenditures:			
Salaries	$276 900	$237 800	$211 800
Printing	337 500	323 800	259 800
Other	196 600	159 500	148 400
Total	811 000	721 100	620 000
Favorable Operating Balance	. . .	$93 500	$28 400
Operating Deficit	$16 400	. . .	. . .
Net Assets:			
Real Estate	$295 200	$244 800	$184 800
Investments and Cash	797 000	776 950	733 900
Equipment	29 700	22 800	22 500
Total	1 121 900	1 044 550	941 200
Asset Equity of Each Member	$145	$138	$128
Number of Members	7 762	7 581	7 342
Pages of Publications	8 088	8 518	15 747
Number of Employees	65	60	56

likewise would have reflected in its work this favorable situation, and we find this the case.

From the progress reports of our many technical committees that have been published in the ASTM BULLETIN and from the annual reports being presented at the Annual Meeting, it is evident great progress has been made in developing new specifications and standard test methods and also in advancing our knowledge of the properties and tests of materials.

As noted later careful consideration is being given to several new areas of work, and there have been significant developments in materials fields where the Society has had active committees working for many years. New demands on the part of designers, more rigorous operating conditions, and other factors combine to require consistently better and better materials. Usually this means more rigorous testing and inspection, but these procedures cannot be standardized until there are available reliable data—and specifications require sound test methods. It is in these areas that ASTM has and will continue to work effectively.

The membership continues to grow. It is encouraging that so many companies during the past year have decided to become sustaining members. This has been one of the most significant membership years, reflecting what we hope is an appreciation of the intensive work that is carried on and indicating also the excellent support the Society enjoys from industry. This is not to minimize in any way the close and fruitful contacts which continue with many branches of government, both Federal and state. The Department of Defense, the General Services Administration, the National Bureau of Standards, and many other Federal departments, and an increasing number of branches of the various state governments cooperate very closely in our work, contributing the time and talents of their technical workers. This cooperation is most important because it tends to prevent duplication of effort and is helpful in coordinating industry and government standards.

An effort is made in this report to note some of the activities and accomplishments during the past year. But considering the far-flung nature of our work, one must look to the committee reports or technical publications and in the news columns of the ASTM BULLETIN for details. In these sources we constantly endeavor to provide our members with full information on the significant advances that are made.

In all of our work cooperation is essential between the representatives of producers and consumers, between committee officers and the Headquarters' Staff, between the Society and other interested groups, and between our Staff and those of other societies. The very splendid cooperation that has been realized in these and other areas is inspiring.

Technical Activities

No single group of men nor any specific procedure can insure that the Society will be alert to all of the needs of industry which it would be logical for the Society to attempt to fill in the field of standards and research in materials. But through the alertness of the officers of our hundreds of technical committees, the administrative officers of the Society, and the Staff, many areas are noted each year where, as a result of careful consideration by those concerned—representatives of the consumer, producer, and very frequently areas in government

—work can be initiated with beneficial results.

A few areas in which new activities have or will shortly be undertaken are noted below, as are certain subjects already under study. This is by no means a complete list.

Study of New Activities

Plastic Pipe and Fittings and Reinforced Plastics:

Fast-growing interest in these materials led Committee D-20 on Plastics, after holding conferences at which interested parties outlined their suggestions, to appoint two new subcommittees. One of these, Subcommittee XVII on Plastic Pipe and Fittings, functions as a joint committee of the Society of the Plastics Industry and ASTM. The second, Subcommittee XVIII, on Reinforced Plastics, operates as a regular subgroup in Committee D-20.

Materials for Electronic Tubes:

As indicated later, a new committee is being established to cover materials for electronic tubes and semiconductor devices. This modification caused a change to be made in the scope of the committee from which it has sprung, namely, Committee B-4 on Electrical Heating, Resistance, and Related Alloys. Its work will cover several different materials, metallic and nonmetallic.

Foamed or Expanded Plastics:

The growing use of these materials which include vinyl and polyurethane foams, which are similar to sponge rubber in properties, and also rigid foams such as those made from polystyrene, cellulose acetate, and urea and phenolic resins, brought about a study of a policy for the Society regarding technical activities, especially test methods. There are several committees directly concerned, for example, those on rubber products, thermal insulating materials, structural sandwich constructions, and plastics. At a conference of these groups with representatives also from the Society of the Plastics Industry and the Society of Plastics Engineers, it was recommended that ASTM organize a coordinating committee on cellular materials having two main functions: (1) allocation of activities to various existing groups, and (2) correlation of information and facilitation of exchange of information among various interested committees. The recommendation is justified on the basis that the existing committee structure is not disturbed, and each group can continue appropriate activities on cellular materials. The coordinating committee will provide a single point of contact within the Society for outside groups interested in cellular materials.

Synthetic Hydraulic Fluids:

A conference is being scheduled to determine whether constructive results would come from undertaking standardization studies in this field, particularly standardization of tests. Increasing use of the materials for the purpose of transmission, etc., and problems of flammability and the like would, in the opinion of some, justify such a committee.

Fuller's Earth:

This material is used in the petroleum industry, by the manufacturers of floor cleaning materials, and elsewhere, and several of the producing companies have indicated they would support a program to develop standard tests. A conference is to be held to review this question.

Manganese Dioxide for Batteries:

Some work has been under way in an industry-government committee to develop standard specifications and tests.

ASTM may be asked to consider fitting this work into its standardization program.

Carbon Black:

For some time a committee in the carbon black industry has been developing test methods. Recognizing the considerable interest in several ASTM committees, for example, rubber products, petroleum, paint, cement, and possibly others, the Society will hold a conference to evaluate the best means of undertaking this work in cooperation with the industry committee. Perhaps a separate technical committee would be most logical.

Casein:

Although a proposal has been received that Committee D-6 on Paper and Paper Products be asked to include this material in its studies, it is obvious that other industries are concerned as well. The extent of the interest is now being ascertained.

Ion Exchange Resins:

The use of these materials in water conditioning has led ASTM Committee D-19 on Industrial Water to organize a new subcommittee. The materials also are used in the chemical analysis of metals, and Committee E-3 may have some interest.

The above list of projects and studies is indicative of considerable new technical work. New subcommittees are constantly being appointed to evaluate problems, and in general these are noted in the annual reports of the committees or in the ASTM BULLETIN. As an example there is a new section in Subcommittee VI on Steel Forgings of Committee A-1 to consider the brittle failure of heavy forgings. This is a vitally important subject, particularly to the manufacturers of large turbines and generators

Committee Titles, Scopes, and Jurisdiction

Committee B-4 on Metallic Materials for Electrical Heating, Electrical Resistance, and Electrical Contacts:

The rapid growth of the electronic industry and the great increase in the use of electron tubes and related materials resulted in considerable expansion of the work on metallic materials for radio tubes carried on in Subcommittee VIII of Committee B-4 on Electrical Heating, Resistance, and Related Alloys. In order to handle this more effectively and at the same time to consider other materials not now being covered but which form the components that go into electron tubes and such products, it was proposed to cover this work in a new technical committee and, accordingly, to modify the scope of the older Committee B-4. Considerable thought and effort has been devoted to the study on which these decisions were based, and it is expected the new committee will have a very active program. In this connection it is of interest to note that the former Subcommittee VIII was the sponsor of numerous specifications and tests.

The new committee is of particular interest also since it is aimed to cover "end use," in contrast to the work of many committees which are confined largely to a specific family of materials —steel, concrete, etc. The work of this new group will entail studies of metallic materials, glass, ceramics, and other materials going into the products of the electronic industry.

The following titles and scopes are recommended:

For Committee B-4:

Title.—Committee B-4 on Metallic Materials for Electrical Heating, Electrical Resistance, and Electrical Contacts.

Scope.—The formulation of specifications and methods for testing metallic materials used in the construction of electrical heating devices, electrical resistance devices, electrical contacts, thermosensitive elements in thermostats, as well as the stimulation of research and standardization of nomenclature to accomplish the foregoing purposes.

For the new committee:

Title.—Committee F-1 on Materials for Electron Tubes and Semi-Conductor Devices.

Scope.—The formulation of specifications and methods of testing materials used in the construction of electronic devices, as well as the stimulation of research and standardization of nomenclature. Electronic devices include electron tubes of all kinds, electric discharge devices, and semi-conductors.

Committee B-8 on Electrodeposited Metallic Coatings:

To clarify its responsibility for chemically reduced metallic coatings, it is recommended that the scope of Committee B-8 be changed from its present form to read as follows:

Scope.—To prepare specifications for electrodeposited and chemically reduced metallic coatings of all kinds on all types of base materials, subsequent treatments of such coatings, methods of testing these coatings, and materials required for their production; including all pertinent investigations of the substrates, the methods of production, the properties of these deposits and their performance under conditions of use and test; excluding only specifications for metal products to which such coatings are applied.

This change was considered by Committees A-5 on Corrosion of Iron and Steel and C-22 on Porcelain Enamel, and these groups have no objection to the proposal.

Committee C-13 on Concrete Pipe:

In order that Committee C-13 would cover concrete pipe used for drainage, this application not having previously been explicitly set forth in its scope, the words "and drainage" have been added to the scope, the revised scope now reading as follows:

Scope.—The formulation of specifications, methods of test for concrete pipe (reinforced and unreinforced) used for constructing sewers, culverts, and for irrigation and drainage.

Requirements for Drain Tile:

Currently the specifications for drain tile, both clay and concrete tile, are the responsibility of Committee C-15 on Manufactured Masonry Units, a single document, Specifications C 4, having been extensively revised in 1950. As a result of several discussions in the Subcommittee on Drain Tile and among the manufacturers and users, it has been proposed that jurisdiction over clay drain tile be assigned to Committee C-4 on Clay Pipe and the concrete drain tile be given to Committee C-13 on Concrete Pipe. Because of divergent opinions in the technical committee, the Board feels that no change in the present setup should be made, pending further clarification and agreement.

Soil Conditioners:

Although it had been thought that work on soil conditioners would be carried on in a joint committee of the ASTM and the Association of Official Agricultural Chemists, further discussions and later evaluation of the interest in these materials resulted in a decision to discontinue the joint committee and to assign to Committee D-18 on Soils for Engineering Purposes, which had desired to take on this responsibility, the task of developing necessary standards and carrying out research where desired. A new section has accordingly been set up in Committee D-18.

Packaged Mortars and Dry Concrete Mixes:

Committee C-9 on Concrete and Concrete Aggregates has assumed responsibility for providing desirable standards for dry concrete mixes and packaged mortars, which materials are being marketed in greatly increased volume. Since Committee C-12 on Mortars for Unit Masonry is concerned also, it has been agreed that Committee C-12 will be fully apprised of the activities; and if at a later date packaged mortars come into sufficient use to justify joint jurisdiction, further consideration will be given to the situation.

District and Related Activities

The support of the ASTM districts in promoting the work of the Society becomes increasingly evident if one compares the 29 district meetings held during 1954–1955 with the 20 meetings of two years ago. In addition, several special meetings were held as noted.

District-sponsored or local meetings were held in several areas not previously thought to be sufficiently large centers of ASTM membership to warrant such activities. All were considered quite successful by both the President and Executive Secretary. Included were such localities as Rome, N. Y., Bartlesville, Okla., Denver, Colo., and Durham, N. H.

Local sections of other groups which cosponsored many meetings included TAPPI, ASM, ASME, Engineers Club of St. Louis, New York State Society of Professional Engineers, SAE, American Rocket Society, Western Society of Engineers, Missouri Society of Professional Engineers, Engineers Club of Bartlesville, Tacoma Engineers Club, and Pittsburgh Association of Purchasing Agents.

President Norman L. Mochel, continuing the practice established by preceding presidents of the Society, was the chief speaker at many of the meetings. His Western trip covered about 10,000 miles.

The Chicago District arranged the dinner and entertainment for the 1954 Annual Meeting and, in addition, sponsored the ladies' entertainment.

The Ohio Valley District arranged to have one of its district meetings coincide with the 1955 Spring Meeting and Committee Week in Cincinnati.

The Philadelphia District is planning to sponsor the dinner and entertainment for the 1955 Annual Meeting in Atlantic City and has also arranged an interesting program for the ladies.

In previous years a rather detailed table has listed data on the Society's meetings but because all meetings are covered in some detail in the ASTM BULLETIN, only the dates and locations are given in the table on the next page.

In connection with this table, the meetings designated as local area meetings are those which were held in a particular city. At these, local ASTM members met with the President and Executive Secretary.

Although many of the ASTM district meetings were held in conjunction with other societies, the special reference to a few joint meetings as noted indicates those areas which have not yet been formalized as ASTM districts.

National Meetings

1954 Annual Meeting

The Society's 57th Annual Meeting was held in Chicago, June 13–18, at the Hotels Sherman and Morrison. There were 36 technical sessions with 110 technical papers; some 600 meetings of technical committees; the largest apparatus exhibit yet held; and the biennial technical photographic display. Attendance totaled 2224, in addition to 178 ladies.

Annual Meeting:		
1954 Annual Meeting	June 13–18, 1954	Chicago, Ill.
Committee Week and Spring Meeting:		
1955 Committee Week and Spring Meeting	January 31–February 4, 1955	Cincinnati, Ohio
District or Special Local Meetings:		
Ohio Valley District	October 7, 1954	Dayton, Ohio
Philadelphia District	October 13, 1954	Philadelphia, Pa.
St. Louis District	October 14, 1954	St. Louis, Mo.
New York District	October 15, 1954	New York, N. Y.
Pittsburgh District	October 26, 1954	Pittsburgh, Pa.
New England District	October 28, 1954	Cambridge, Mass.
Northern California District	November 30, 1954	San Francisco, Calif.
New York District	December 8, 1954	Rome, N. Y.
Western New York-Ontario District	December 9, 1954	Buffalo, N. Y.
New York District	January 20, 1955	New York, N. Y.
Chicago District	January 24, 1955	Chicago, Ill.
St. Louis District	January 25, 1955	St. Louis, Mo.
Ohio Valley District	February 2, 1955	Cincinnati, Ohio
Southwest District	February 8, 1955	Bartlesville, Okla.
Kansas City, Mo. (local area meeting)	February 9, 1955	Kansas City, Mo.
Denver, Colo. (jointly with ASM)	February 10, 1955	Denver, Colo.
Richland, Wash. (jointly with ASM, ASME, AIChE, Am. Chem. Soc.)	February 14, 1955	Richland, Wash.
Tacoma, Wash. (jointly with Tacoma Engineers Club)	February 15, 1955	Tacoma, Wash.
Seattle, Wash. (jointly with ASM)	February 16, 1955	Seattle, Wash.
Portland, Ore. (local area meeting)	February 17, 1955	Portland, Ore.
Northern California District	February 23, 1955	Oakland, Calif.
Southern California District	February 24, 1955	Los Angeles, Calif.
Southwest District	March 1, 1955	Houston, Tex.
Southwest District	March 3, 1955	Dallas, Tex.
Chicago District	March 15, 1955	Chicago, Ill.
Philadelphia District	April 12, 1955	Philadelphia, Pa.
Cleveland District	April 20, 1955	Cleveland, Ohio
Detroit District	April 21, 1955	Detroit, Mich.
New England District	April 28, 1955	Durham, N. H.
Pittsburgh District	May 17, 1955	Pittsburgh, Pa.
New York District	May 26, 1955	New York, N. Y.

Features of the meeting were covered in the July, 1954, ASTM BULLETIN. The Chicago District acted as hosts, providing an outstanding program of entertainment and aiding in other important ways, including directing the photographic exhibit.

1955 Committee Week and Spring Meeting

Committee Week was held in Cincinnati, January 31–February 4. The Spring Meeting featured a Symposium on Basic Effects of Environment on the Strength, Scaling, and Embrittlement of Metals at High Temperatures, sponsored by the Joint ASTM-ASME Committee on Effect of Temperature on the Properties of Metals. There were approximately 300 meetings of committees during the week with a registered attendance of 1017.

Future Meetings

Annual Meetings of the Society have been scheduled as follows: June 26–July 1, 1955; June 17–22, 1956; June 16–21, 1957—Atlantic City, N. J.; June 22–27, 1958—Boston, Mass.; June 21–26, 1959; June 26–July 1, 1960—Atlantic City.

Committee Week and Spring Meetings: February 27–March 2, 1956, Buffalo, N. Y.; February 4–8, 1957, Philadelphia, Pa.; February 9–14, 1958, St. Louis, Mo.

1956 Pacific Area Meeting

Much activity is under way in the planning for the Second Pacific Area National Meeting in Los Angeles, September 16–22, 1956. The General Committee on Arrangements and its subcommittees have held meetings, the technical program is being drafted, and with the enthusiasm evident on the Coast and the fine collaboration between the Northern and Southern California Districts, an outstanding meeting is in prospect.

An imposing group of technical committees are planning meetings, and several of them also will sponsor symposiums or technical sessions. These include the following fields: electrodeposited metallic coatings, cement, lime, concrete and concrete aggregates, structural sandwich constructions, paint, petroleum products and lubricants, road and paving materials, wood, bituminous waterproofing and roofing materials, soils for engineering purposes, industrial water, and others.

Membership

On May 1, 1955, the membership of the Society totaled 7911, compared with a total of 7615 one year ago. Gains and losses in various classes of membership are shown in the following table:

Class of Membership	Membership		Losses				Additions		Total		
	May 1, 1954	May 1, 1955	Resignations	Dropped	Death	Transfer	Transfer	Election	Loss	Gain	Increase
Honorary	20	21	...	...	1	...	2	...	1	2	1
Perpetuity and Life	11	11	...	...	...	...	...	...	...	...	...
Sustaining	274	345	3	...	...	1	72	3	4	75	71
Company, Firm, etc.	1788	1797	38	9	...	80	14	122	127	136	9
Individual, etc.	5433	5652	209	87	47	15	27	550	358	577	219
Junior	89	85	6	9	...	19	...	30	34	30	4[a]
Total	7615	7911	256	105	48	115	115	705	524	820	296
Student	359	454	29	150	...	12	...	286	191	286	95

[a] Net loss.

It is interesting to compare our present membership of 7911 with the figures for ten and twenty years ago; in 1945 our total membership was 5649, and in 1935 it was 3612.

Sustaining Members:

There have been 77 new sustaining members, three resignations, and one sustaining member transferred to company class. The new sustaining members are:

Air Reduction Co.
Alan Wood Steel Co.
Allegheny Ludlum Steel Corp.
Allen-Bradley Co.
Allentown Portland Cement Co.
Allis-Chalmers Manufacturing Co.
American Can Co.
American Felt Co.
American Oil Co.
Anaconda Wire and Cable Co.
Ashland Oil and Refining Co.
Baldwin-Hill Co.
Bethlehem Pacific Coast Steel Corp.
Boston Edison Co.
The Budd Co.
Byerlyte Corp.
Calumet Division, Calumet & Hecla, Inc.
Canadian National Railways
Champion Spark Plug Co.

The Chesapeake & Ohio Railway Co.
Clevite Corp., Research Center
Collins Radio Co.
Continental Can Co., Inc.
Corning Glass Works
Cummins Engine Co., Inc.
Dayton Malleable Iron Co.
Detroit Testing Laboratory, Inc.
Dragon Cement Co., Inc.
Dunlop Tire and Rubber Corp.
Duquesne Light Co.
Eastern Stainless Steel Corp.
Ebasco Services, Inc.
Ethylene Chemical Corp.
Federal Portland Cement Co., Inc.
Ferro Corp.
Fisher Scientific Co.
The Fluor Corp., Ltd.
The Formica Co.
Fruehauf Trailer Co.
The General American Transportation Corp.
General Aniline and Film Corp.
Giant Portland Cement Co.
Gladding, McBean and Co.
Glens Falls Portland Cement Co.
Grinnell Co., Inc.
The Harshaw Chemical Co.
Hercules Cement Corp.
Hughes Research and Development Labs., Hughes Aircraft Co.
Imperial Oil, Ltd.
International Resistance Co.
Joslyn Manufacturing and Supply Co.
Kaiser Steel Corp.
A. & M. Karagheusian, Inc.
Kelsey-Hayes Wheel Co.
Keystone Portland Cement Co.
Linde Air Products Co., Div. of Union Carbide and Carbon Corp.
Arthur D. Little, Inc.
The Lubrizol Corp.
Mexican Light and Power Co., Ltd.
Mundet Cork Corp.
Nazareth Cement Co.
North American Aviation, Inc.
North American Cement Corp.
The Ohio Oil Co.
Owens-Corning Fiberglas Corp.
Pepperell Manufacturing Co.
Radio Corp. of America
Riverside Cement Co.
Spencer Chemical Co.
Tide Water Associated Oil Co.
United States Plywood Corp.
Virginia Electric and Power Co.
Warner Co.
Weirton Steel Co.
The Western Union Telegraph Co.
Whitehall Cement Manufacturing Co.

50-Year Members:

There are three individuals and five organizations as noted below that have been connected with the Society continuously for 50 years, having joined in 1905:

H. C. Berry
W. C. Hanna
R. H. Harry Stanger
Engineers' Society of Western Pennsylvania
Marquette Cement Manufacturing Co.
Pittsburgh Testing Laboratory
Worcester Polytechnic Inst.
York Corp.

These members will be recognized at the Annual Meeting.

40-Year Members:

There are 40 members who this year have completed 40 years of membership, bringing the total number of certificates issued to the "Forty-Year Club" to 314. The members who will receive the 40-Year Certificates at this Annual Meeting are as follows:

Julius Adler
University of Akron, Bierce Library
Alpha Portland Cement Co.
The Babcock & Wilcox Co.
Hyman Bornstein
Forest Products Laboratories of Canada
The Central Railroad Co. of New Jersey
Certain-teed Products Corp.
Harold F. Clemmer
Concrete Products Company of America
Irving H. Cowdrey
R. Robertson Deans
Deere and Co.
E. I. du Pont de Nemours & Co., Inc., Pigments Dept.
Ecole Polytechnique
Erie Forge and Steel Corp.
Fay, Spofford & Thorndike
Walter H. Flood
Glens Falls Portland Cement Co.
James E. Heckel
George A. Johnson
Keasbey & Mattison Co.
C. F. Kettering
A. E. Legg
F. B. Lysle
Paul D. Merica

Moody Engineering Co.
NATCO Corp.
New York Public Library, Reference Dept.
North American Cement Corp.
Patton Clay Manufacturing Co.
Pittsburgh Testing Laboratory
Rhode Island Department of Public Works, Division of Roads and Bridges
Richard E. Schmidt
Scott Testers, Inc.
Fred B. Seely
Oliver W. Storey
United States Metals Refining Co.
Country Roads Board of Victoria, Australia
Franklin A. Wertz

Deaths:

The Society has lost the following 48 members through death (figures in parentheses are dates of membership):

Benham, Webster L. (1946)
Berg, W. H. C. (1952)
Bowles, James T-B. (1921)
Browall, Harold W. (1947)
Bryant, Earl R. (1953)
Burns, Robert (1951)
Corbett, Walter E. (1930)
Daniels, John C. (1949)
Dickerson, N. K., Sr. (1950)
Geary, D. S. (1945)
Goldman, Meyer (1946)
Guy, T. W. (1933)
Herbst, Henry W. (1952)
Hess, Wendell F. (1945)
Hoyt, Lester F. (1939)
Jacobus, David S. (1923)
Jenkins, George A. (1951)
Johnson, Leon H. (1941)
Loving, M. W. (1922)
Lyons, Earl W. (1951)
Mactaggart, E. F. (1949)
Malan, Lowell (1942)
Marrocco, Guy D. (1942)
Marvin, Walter (1953)
Mueller, Fred R. (1945)
Mulligan, John A. (1941)
Nicholson, C. M. (1952)
Osborne, Raymond J. (1907)
Palmer, Ralph M. (1949)
Passos, Edison Junqueira (1931)
Patterson, Edward J. (1939)
Porter, Alfred J., Jr. (1933)
Queale, William (1952)
Quinn, T. S. (1932)
*Rawdon, Henry S. (1917)
Schlyter, Ragnar Olaf Oskar (1947)
Schniewind, H. Z. (1930)
Schuessler, Harry O. (1929)
Schwartz, Harry A. (1907)
Sohn, Edwin (1934)
Steiner, W. E. (1935)
Tompkins, E. J. (1943)
Upson, Willard (1941)
Van Trump, Isaac (1909)
Weisberg, Herman (1951)
Whittemore, Herbert L. (1911)
Witmer, Francis P. (1910)
Young, Roderick B. (1916)

In addition to the above, the following representatives of company members of the Society passed away:

Benjamin Baskin, Concrete Products of America
E. P. Bolin, Chicago Vitreous Enamel Products Co.
Art Brown, The Arundel Corp.
A. H. Bunte, Colorado State Highway Dept.
F. L. Castleman, Jr., University of Connecticut, School of Engineering
John C. Day, Western Petroleum Refiners Assn.
George DeLisle, Kelsey-Hayes Wheel Co.
Samuel Dultzin, Equipos Industriales, S.A.
L. R. Eastman, Frederick B. Stevens, Inc.
A. R. Ellis, Pittsburgh Testing Laboratory
Gustaf A. Gaffert, Sargant & Lundy
K. A. Horn, Congoleum-Nairn, Inc.
H. E. Koehler, Koehler Instrument Co., Inc.
M. C. Madsen, Northern Natural Gas Co.
W. A. McCaffrey, Canadian Standards Assn.
J. A. McNiven, Port of New Orleans, Board of Commissioners
Douglas J. Peake, Florence Pipe Foundry and Machine Co.
T. Rosevelt, Sun Chemical Corp.
Harry E. Rowell, Columbia Steel and Shafting Co.
Homer X. White, Oklahoma Department of Highways
C. A. Yeatman, Shell Oil Co.

A number of these men had been affiliated with the Society for many years and rendered outstanding services, particularly through work on the technical committees. The various issues of the ASTM BULLETIN have included appropriate notices and appreciation of their work.

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* Honorary Member.

Honors and Awards

During the year the Board's Committee on Lectures and Awards issued its Manual on Special Lectures, Honors, and Awards. This is distributed to the committees that make recommendations on the award recipients.

Descriptions of the various awards as well as the personnel of the lecture and award committees are given in the ASTM Year Book.

Recipients of honors to be given at the 1955 Annual Meeting are indicated below.

Award of Merit:

R. C. Adams
B. J. Barmack
E. J. Kilcawley
C. E. Loos
R. J. McKay
W. T. Pearce
N. C. Rockwood
R. B. Sosman
G. N. Thompson
W. S. Young
W. A. Zinzow

Recognition of Technical Papers:

Charles B. Dudley Medal (research).—No award.

Richard L. Templin Award (testing).—M. S. Hunter and W. G. Fricke, Jr., for their paper "The Metallographic Aspects of Fatigue Behavior."

Sam Tour Award (corrosion).—No award.

Sanford E. Thompson Award (concrete, sponsored by Committee C-9).—R. C. Mielenz for his paper "Petrographic Examination of Concrete Aggregates."

C. A. Hogentogler Award (soils, sponsored by Committee D-18).—H. G. Mason, J. A. Bishop, L. A. Palmer, and P. P. Brown for their paper "Piles Subjected to Lateral Thrust."

Recognition of Outstanding Contributions:

Harold DeWitt Smith Memorial Medal (textiles).—John H. Dillon, Director, Textile Research Institute, Princeton, N. J.

Max Hecht Award (industrial water, sponsored by Committee D-19).—Everett P. Partridge, Director, Hall Laboratories, Inc., Pittsburgh, Pa.

Finances

Report for 1954:

Full details of the fiscal operations of the Society for 1954 are included in the report of the auditors appearing in Appendix I.[1]

Operating Receipts:

Total operating receipts were $794,546. Of this amount receipts from dues and entrance fees were $236,346 or 29.8 per cent; receipts from sales of publications were $470,459 or 59.2 per cent; and receipts from miscellaneous sources consisting principally of advertising, income from investments, apparatus exhibit, and registration fees totaled $87,741 or 11.0 per cent.

It will be noted that receipts from membership fees are again under 30 per cent of the total for the second consecutive year.

Operating Disbursements:

Total disbursements were $810,988, which included $60,000 earmarked but not spent for the 1955 Book of Standards. Thus, we ended the year with a deficit of about $16,400, compared to our estimated deficit of $41,000, and it should be remembered we did not actually use the $60,000 for the Book of Standards.

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[1] See p. 62.

About $337,500 were spent for publications. Total salaries were $276,850, which included considerable extra help during the summer; salaries represented about 34 per cent of total disbursements. In moving part of the Staff to the newly procured Cherry St. building, a considerable sum was spent for new furniture and fixtures. Of $80,000 for general office expense, over $31,000 were for postage and shipping costs; this gives some idea of the volume of distribution of our publications. Costs of Blue Cross, Group Life Insurance, Social Security, and retirement payments, representing 9.9 per cent of salary costs, totaled about $27,500.

Balance Sheet:

On December 10 our total assets in General Fund were $683,646 compared to $612,858 a year ago. In all funds, General, Building, Medal, etc., total assets were $1,253,398 compared with $1,195,404 a year ago. It should be pointed out that in the Balance Sheet no account has been taken of the assets of the Society in the form of publications in stock. This is consistent with many years' practice in this respect and, of course, results in a more conservative statement. An inventory of the principal technical publications as of May 1, 1955, is summarized below:

Proceedings (All back copies including 1954)	3 429
1952 Book of ASTM Standards	
Part 1	8
Part 2	289
Part 3	818
Part 4	517
Part 5	815
Part 6	583
Part 7	799
1953 Supplement to Book of Standards	
Part 1	1 989
Part 2	1 661
Part 3	1 509
Part 4	1 995
Part 5	1 880
Part 6	1 627
Part 7	1 900
1954 Supplement to Book of Standards	
Part 1	2 314
Part 2	1 768
Part 3	1 055
Part 4	1 690
Part 5	1 382
Part 6	1 464
Part 7	1 508
ASTM Methods of Chemical Analysis	585
Special Compilations of Standards	14 686
Selected Standards for Students	10 550
Symposiums and Special Reprints, STP's, etc.	121 618
Reprints of Standards (Approx.) (2064 × 110)	227 000
Radiographic Standards for Steel Castings	23
Radiographic Standards for Aluminum and Magnesium Castings	19

Not included in inventory

(1) Viscosity Temperature Charts
(2) Hardenability Charts
(3) Knock Test Manual and Supplement
(4) Marburg Lectures
(5) Cotton Yarn Boards
(6) Petroleum Charts

Building Fund:

Last year our report explained various real estate transactions, including the purchase of a building on Cherry St. and the disposal of a portion of a large lot purchased in 1952. This year we sold a portion of the newly procured Cherry St. lot to our neighbor, the Moore Institute of Art, who will soon start their large new building. It is of interest that the three educational institutions already occupying most of this block have now procured all of it.

We received about $15,000 for the lot on 1929 Cherry St. This transaction, taking place in February, 1955, is not reflected in the Balance Sheet for the Building Fund as of December 10, 1954.

Assets in the Building Fund, which include the current Race St. Headquarters, the Cherry St. property, and the balance of the lot immediately adjoining this, total $322,064.

As liabilities the Balance Sheet shows all contributions from members and from other ASTM funds, accumulated income, interest, proceeds from the lot sales in excess of the cost, and the loan from ASTM General Funds which enabled the procurement of the Cherry St. property.

Investments:

Investments of Society Funds (General, Building, Research, Committee, Medal and Lecture Funds) as of December 10, 1954, are given in the appended auditors' report,[1] both book and market values being shown. As of that date the book value of all investments was $511,875, compared with $448,814 a year ago; the market value of all investments was $631,618, 23 per cent above book value.

The following changes in investments during the calendar year 1954 are listed as a matter of record:

GENERAL FUNDS

Sold *Bonds*

$15 000 U. S. Treasury Bonds 2% (matured) converted to U. S. Treasury Bonds 2½% 1961.
$15 000 U. S. Treasury Bonds 2% (matured) converted to U. S. Treasury Bonds 2½% 1963.
$5 000 U. S. Government "G" Bonds—$5 000.

	Profit or Loss (−)
$15 000 U. S. Treasury Bonds 2¼% 1955–1953	$185.56
Common Stock	
60 sh. American Viscose ($2214.69)	−108.89

Bought *Bonds*	*Cost*
$5 000 Southern National Gas	$5 109.81
5 000 American Tobacco	5 067.08
3 000 Pacific Gas & Electric	3 090.57
Preferred Stock	
30 sh. Armstrong Cork	$2 947.09
30 sh. Lorillard	4 380.00
30 sh. Long Island Lighting	3 015.00
30 sh. Mississippi Power & Light	3 075.00
30 sh. Westinghouse Electric	3 067.74
30 sh. Philadelphia Electric	3 285.00
30 sh. Endicott Johnson	2 937.50
10 sh. American Cyanamid	1 019.75
30 sh. Allegheny Ludlum	3 037.34
30 sh. Consolidated Edison	3 286.08
Common Stock	
30 sh. Atchison, Topeka & Santa Fe	$2 961.06
30 sh. Union Carbide & Carbon	2 204.44
50 sh. Sears Roebuck	3 137.78
50 sh. International Nickel of Canada	1 925.00
50 sh. Penna. Power & Light	2 083.20
50 sh. Parke Davis	1 641.19
50 sh. Chas. Pfizer	1 732.94
25 sh. American Telephone & Telegraph	4 233.00
50 sh. Johns Manville	3 433.25
40 sh. Westinghouse Electric	2 737.10
70 sh. Houston Light & Power	2 426.69
30 sh. Climax Molybdenum	1 285.23
21 sh. Philadelphia Electric (Subscription $34.00)	714.34
50 sh. General Telephone	50% Stock Dividend
50 sh. General Electric	Split 2 for 1
8 sh. Gulf Oil	Stock Dividend
Mutual Funds	
169.810 sh. Commonwealth Investment (Dividend)	$1 185.86
40 sh. Eaton and Howard Balanced Funds	1 251.60
2131 sh. Eaton and Howard Balanced Funds	Split 2 for 1
1011 sh. Fundamental Investors	Split 2 for 1
Total Bonds, Preferred and Common	$73 833.18
Total Mutual Funds	2 437.46
Total	$76 270.64

BUILDING FUND

(No Activity)

RESEARCH FUND

Sold	*Proceeds*
$3 000 U. S. Government "G" Bonds (Matured)	$3 000.00
Bought	*Cost*
$4 000 Socony Vacuum Oil (Bonds)	$3 899.85
2 000 Pacific Gas and Electric (Bonds)	2 060.21
30 sh. General Motors (Preferred)	3 755.80
47 sh. Standard Slag (Gift)	2 115.00
6 sh. Eaton and Howard Balanced Funds (Dividend)	187.74
353 sh. Eaton and Howard Balanced Funds	Split 2 for 1

TEMPLIN FUND

Bought	*Cost*
1 sh. Eaton and Howard Balanced Funds (Dividend)	$31.29
36 sh. Eaton and Howard Balanced Funds	Split 2 for 1

TOUR FUND

Bought	*Cost*
1 sh. Eaton and Howard Balanced Funds (Dividend)	$31.29
53 sh. Eaton and Howard Balanced Funds	Split 2 for 1

COMMITTEE FUNDS (X-RAY DIFFRACTION)

$20 000 U. S. Treasury Bonds 2% 1954 (Matured) converted to 2½% 1963.

It will be noted that about $74,000 was invested in bonds and preferred and common stocks, in several cases adding to previously purchased commons. This is reflected in the considerable appreciation of our portfolio and the greater dividends received.

Total income from interest and dividends in all funds, including returns on mutual funds and interest on savings accounts, was $32,743. In 1953 the comparative figure was $25,874.

1955 Budget:

The budget for 1955 shows a deficit of $59,000. This is the third year in our triennial year of publication of the Book of Standards, and income from sales will certainly not approach that of the first year after the book is issued. We must always consider our operations are on a three-year basis.

As detailed in the February, 1955, BULLETIN, dues and entrance fees are expected to bring $240,000, publication sales $416,500, and miscellaneous $75,500, totaling $732,000.

Estimated publication costs of $295,000, salaries $300,000, and general office expense $79,500, together with other operating costs, bring estimated disbursements of $791,000.

The Finance Committee hopes that the income may be quite a bit higher, and that the efforts to keep down costs will result in a deficit much less than budgeted.

To complete reference to 1955 finances thus far this year, it is noted that during the first four months the following changes in investments have taken place:

GENERAL FUNDS	
Bought	*Cost*
*90 sh. Eaton & Howard Balanced Fund	$1 707.30
*73 sh. Fundamental Investors Inc.	946.08
*86.251 sh. Commonwealth Investment Co.	963.46
Matured	*Proceeds*
$6 000 U. S. "G" Bonds	6 000.00
RESEARCH FUNDS	
Bought	*Cost*
10 sh. General Motors Corp.	$753.88
*15 sh. Eaton & Howard Balanced Fund	284.55
Matured	*Proceeds*
$1 500 U. S. "G" Bonds	1 500.00
TEMPLIN AWARD FUND	
Bought	*Cost*
*1 sh. Eaton & Howard Balanced Fund	$1 897.00
SAM TOUR AWARD FUND	
Bought	*Cost*
*2 sh. Eaton & Howard Balanced Fund	$3 794.00
COMMITTEE FUNDS	
Matured	*Proceeds*
$1 000 U. S. Treasury Bonds 2⅞%	$1 000.00

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* Capital Gains Dividend Shares.

The management of any investment fund is fraught with problems. It seems wise that in the past two years the Finance Committee has invested sizable sums in common stocks and also increased modestly our holdings of preferreds. The Investment Advisory Committee, independent of the Finance Committee, studies our portfolio and our cash position at intervals and makes recommendations to the Finance Committee.

Currently it is expected that we will continue to hold virtually all of our various securities, and if further purchases of common stocks are to be made, they will be very modest, purchases spread out over several months to take into account dollar cost averaging.

At the end of March, the sum of our cash, bonds, and preferred stocks represented 70.0 per cent, the common stocks and the two common stock mutuals representing 30.0 per cent. (This excludes the two balanced mutual funds.)

Rearrangement of Investment Funds:

It is proposed that we simplify the handling of our investments by combining in one so-called "investment fund" all of our holdings from the various separate funds, General, Building, Committee, etc., then apportion to those funds, on the basis of the book value contributed, the income received and the market appreciation that may result.

Employee Benefits

To supplement the Blue Cross hospitalization plan for the Headquarters Staff, the Directors approved a group major medical insurance policy which became effective in March, applicable to the entire full-time Staff. This is the usual type that a growing number of organizations are assuming. It provides that after the payment of the basic benefits, such as Blue Cross, Blue Shield, or both, plus $100 from the employee, the major medical plan will underwrite three fourths of the balance of the charges for hospital, doctors, etc., up to a maximum of $5000. In the case of employees with dependents, the Society has agreed to underwrite approximately half the cost of covering these, which will amount to about $475 per year. The total cost of the major medical plan, including the share for the some eighteen Staff members with dependents, will be about $2125.

Administrative Matters

Proposed Amendment of By-laws

As a result of a conference of leading engineering educators and Society officers, at which consideration was given to student and junior membership and the fostering of closer relations with engineering faculty personnel and schools, it is recommended by the Board of Directors that the term "Associate Membership" supplant that of "Junior Membership" and that the age at which transfer must be made to full membership be deferred from the present twenty-seven years to thirty years. It is also recommended that the dues be modified slightly and that a change be made in publication benefits. (The latter are not covered in the By-laws.) Under the proposed new setup, the Associate Member will be given a choice of receiving the *Proceedings* or one part of the Book of Standards and may procure additional publications at special prices.

To effectuate these changes, the Board recommends that the appropriate sections of the By-laws be amended to read as follows by the deletion of the words in brackets and the insertion of the italicized words:

ARTICLE I. MEMBERS AND THEIR ELECTION

SEC. 1. The Society shall consist of Individual Members, Company Members, Sustaining Members, [Junior] *Associate* Members and Honorary Members.

SEC. 5. [A Junior] *An Associate* Member shall be a person less than [twenty-seven] *thirty* years of age. [A Junior] *An Associate* Member shall have the same rights and privileges of an Individual Member, except he shall not be eligible for office. His status shall be changed from [Junior] *Associate* Member to Individual Member at the beginning of the fiscal year next succeeding his [twenty-seventh] *thirtieth* birthday.

SEC. 6. (last sentence). His status shall be changed to that of [Junior] *Associate* Member or Individual Member upon severance of his connections with the technical school, apprentice course or night school.

SEC. 8 (first sentence). Individual Members, Company Members, Sustaining Members and [Junior] *Associate* Members shall be proposed by two members and elected by the Board of Directors.

ARTICLE VIII. DUES

SEC. 1. The fiscal year shall commence on the first day of January. The annual dues, payable in advance, shall be as follows: For Individual Members, $18; for Company Members, $50; for Sustaining Members, $150; for [Junior] *Associate* Members, [$9] *$10;* for Student Members, $2. Honorary Members shall not be subject to dues.

SEC. 2 (first sentence). The entrance fees, payable on admission to the Society, shall be $10 for Individual Members, Company Members, and Sustaining Members, and $5 for [Junior] *Associate* Members.

Society Headquarters Building:

The use of the remodeled addition to the Headquarters Building, on Cherry St., has alleviated the crowded situation that existed in the original Race St. Building and has enabled more efficient operations. There is considerable room for expansion so that for a few years at least, unless there is some unusual situation arising, there need be no concern about added space or facilities.

Headquarters Staff:

During the year, as announced in the BULLETIN, a new Assistant Technical Secretary was employed, Frank Y. Speight, who joined our Staff on November 1. A graduate in chemical engineering and with considerable experience in the chemical field, he also brings the benefit of several years' work on the Advisory Board on Quartermaster Research and Development. In addition to contacts with various technical committees, he will also assist the Editor in handling the continuing and growing load of publications.

The efficient operation of the Society depends to a considerable extent on an efficient and smoothly working Staff. We are fortunate in having the loyalty and efficient services of our group. The complexity of our operations with so many committees, such varied publications, an increasing volume of editorial matter, and orders for publications keeps the Staff extremely busy in order to keep abreast.

Cooperative Activities

The Society has continued its close cooperation with many other organizations, both technical and scientific societies and trade groups, and we have not lessened our interest and contacts with the various Government departments, including the General Services Administration, which is responsible for Federal Standards, and the Department of Defense.

The Advisory Committee to the National Bureau of Standards held an organization meeting and made certain recommendations to the Bureau which are being considered. Our many other areas of cooperation with the Bureau continue, and new ones constantly are being undertaken.

During the year several conferences were held with representatives of other societies, usually on matters involving standardization. For the most part, these have been reported and covered in the minutes of the Board Meetings.

A special committee of Directors, under the chairmanship of Vice-President C. H. Fellows, has been designated to study our contacts with technical societies, trade associations, and related organizations. A study indicated that some 250 other groups were participating in the work of our technical committees. This measure of cooperation is very significant and, among other attributes, tends to prevent duplication of effort. It is felt very important that we use the talents of engineers and technical people as efficiently as possible, and avoiding duplication seems essential. As this new committee continues its studies, it is expected our areas of cooperation will be extended. Usually the entrance of the Society into a new technical field brings into the orbit of interest some new association or organized group. ASTM welcomes this and wishes at all times to give full credit for the help and services which we receive in such large measure from other organizations.

ASTM was represented at the meetings of the International Union of Testing and Research Laboratories in Norway by Past-President L. J. Markwardt, who was in Europe attending a conference on timber. A most interesting report was received of the work of this group. ASTM has become a member of this Union which is concerned with research problems in the field of building materials and has designated D. E. Parsons, a member of the Board of Directors, as our representative.

American Standards Association:

Close cooperation has continued with the American Standards Assn., and ASTM renominated as one of its representatives on the Standards Council Past-President J. R. Townsend.

A new ASA Materials and Testing Standards Board has now been set up which it is believed eventually will facilitate action on submittals from the ASTM and reduce the time and effort involved. This group comprises the ASTM Administrative Committee on Standards with two additional members designated by ASA. It takes over the work formerly handled by the Miscellaneous Standards Board as related to ASTM.

Respectfully submitted on behalf of the Board of Directors,

N. L. MOCHEL,
President.

R. J. PAINTER,
Executive Secretary.

June, 1955.

APPENDIX I

REPORT OF THE AUDITORS FOR THE FISCAL YEAR JANUARY 1 TO DECEMBER 10, 1954

Philadelphia, January 5, 1955

Mr. R. J. Painter, *Executive Secretary*
AMERICAN SOCIETY FOR TESTING MATERIALS
Philadelphia, Pa.

Dear Sir:

We have examined the books and accounts of the American Society for Testing Materials for the period ended December 10, 1954, the date the Society closed its books for the year 1954. We did not make a detailed audit of all transactions, but made tests to the extent we considered appropriate in determining the accuracy of the accounts.

Cash on deposit in checking and savings accounts, and cash represented by certificates of deposit were verified by direct correspondence with the various depositories and reconciled with the cash records. Accounts receivable were not verified by correspondence with debtors. The investments owned by the Society, as detailed later in this report, were examined by us. Such securities are in safe deposit box of the Society at the Girard Trust Corn Exchange Bank. Income from investments for the period under review was verified by us and found to be properly recorded on the books of the Society.

We have prepared and submit herewith balance sheet as of December 10, 1954, statement of cash receipts and disbursements and operations for the period ended that date, and other supporting schedules which, in our opinion present fairly the financial position of the Society at December 10, 1954, and the results of its operations for the period ended that date.

Respectfully submitted,
John Heins & Co.

BALANCE SHEET AS OF DECEMBER 10, 1954

(Including Special and Designated Funds)

ASSETS

General Funds:				
Cash		$198 844.62		
Less Check No. 3901 as of December 9, 1954 (drawn against estimated cost of 1954 *Proceedings* and 1954 Supplements to Book of Standards)		68 500.00	$130 344.62	
Investments (Market Value $491 885.46)—Cost			391 988.43	
Accounts Receivable			52 523.87	
Loans Receivable (Building Fund)			78 400.12	
Advance for Commercial Directory			229.10	
Advance to Forest Products Laboratory			500.00	
Total Current Assets—General Funds			653 986.14	
Furniture and Fixtures (depreciated book value)			29 660.19	
Total Assets—General Fund				$683 646.33
Building Fund:				
Cash			13 259.54	
Investments (Market Value $13 165.94)—Cost			13 632.83	
Land—Cost			76 159.42	
Building and construction costs		263 612.64		
Less accumulated depreciation		44 600.00	219 012.64	
Total Assets—Building Fund				322 064.43
Other Special and Designated Funds:				
Cash:				
ASTM Research Fund		12 427.68		
Dudley Medal and Marburg Lecture Fund	896.56			
Richard L. Templin Award Fund	1 082.04			
Sam Tour Award Fund	172.55			
F. E. Richart Award Fund	1 010.70			
Total Medal and Lecture Funds		3 161.85		
Committee Funds		125 844.00	141 433.53	
Investments:				
ASTM Research Fund (Market Value $83 403.64)—Cost		63 014.26		
Dudley Medal and Marburg Lecture Fund (Market Value $6 023.75)—Cost		6 625.00		
Richard L. Templin Award Fund (Market Value $1 359.36)—Cost		1 088.49		
Sam Tour Award Fund (Market Value $2 001.28)—Cost		1 600.87		
Committee Funds (Market Value $33 778.14)—Cost		33 925.00	106 253.62	
Total Assets, Special and Designated Funds				247 687.15
Total Assets				$1 253 397.91

NOTE.—All market values of securities are as of December 10, 1954.

LIABILITIES

General Funds:			
Advance Collections		$12 476.53	
Accounts Payable:			
Committee C-1		109.03	
Joint Committee on X-ray Diffraction		109 819.65	
Institute of Petroleum		2 261.41	
Pennsylvania Sales Tax Collections		20.68	
Total Current Liabilities—General Funds		124 687.30	
Life Membership Fund	$3 812.50		
Publication Fund	16 841.80		
Book of Standards Reserve	120 400.18		
Executive Retirement Reserve	13 973.60		
Retirement Fund Reserve	24 339.68		
Reserve for Depreciation of Investments	20 000.00		
Reserve for Additional Cost of Replacement of Headquarters Building	25 000.00		
Special Annual Meeting Entertainment Account	7 586.64		
	231 954.40		
Surplus	327 004.63	558 959.03	
Total Liabilities and Surplus—General Funds			$683 646.33
Building Fund:			
Contributions from Members		175 763.49	
Contributions from ASTM General Funds		56 689.57	
Notes Payable—General Funds		78 400.12	
Accumulated Income, Profit on Investments		11 211.25	
Total Building Fund			322 064.43
Other Special and Designated Funds:			
ASTM Research Fund:			
Principal	71 189.69		
Income	4 252.25	75 441.94	
Dudley Medal and Marburg Lecture Fund:			
Principal	6 625.00		
Income	896.56	7 521.56	
Richard L. Templin Award Fund:			
Principal	2 100.43		
Income	70.10	2 170.53	
Sam Tour Award Fund:			
Principal	1 600.87		
Income	172.55	1 773.42	
F. E. Richart Award Fund:			
Principal	1 000.00		
Income	10.70	1 010.70	
Committee Funds, Unexpended Balance		159 769.00	
Total Special and Designated Funds			247 687.15
Total Liabilities and Funds			$1 253 397.91

COMPARISON OF GENERAL FUNDS FOR FISCAL YEARS 1950–1954 INCLUSIVE.

At Close of Fiscal Year	Assets				Liabilities			
	Cash	Investments	Accounts Receivable	Furniture and Fixtures	Accounts Payable	Reserve for Book of Standards	Miscellaneous Funds	Surplus
1950	$147 957.36	$222 662.96	$50 692.18	$17 959.00	$59 919.59	$61 900.18	$65 973.89	$251 477.84
1951	164 497.75	263 995.13	77 239.16	18 758.61	72 990.86	101 900.18	90 536 48	259 063.13
1952	200 537.56	282 493.36	63 050.85	22 475.95	86 506.97	101 900.18	114 326.31	265 824.26
1953	101 212.48	338 008.56	150 822.09	22 814.82	88 136.41	60 400.18	115 116.97	348 604.39
1954	130 344.62	391 988.43	131 653.09	29 660.19	124 687.30	120 400.18	111 554.22	327 004.63

COMMITTEE FUNDS

Committee A-1 On Steel		$4 066.64
Committee A-5 On Corrosion of Iron and Steel		1 049.21
Committee B-3 On Corrosion of Non-Ferrous Metals and Alloys		2 653.76
Committee B-6 On Die-Cast Metals and Alloys		2 837.56
Committee B-8 On Electrodeposited Metallic Coatings		11.25
Committee C-1 On Cement		1 713.67
Committee C-1 Cement Reference Laboratory		−81.00
Committee C-9 Sanford E. Thompson Medal Fund		1 015.42
Committee C-9 On Concrete and Concrete Aggregates		149.71
Committee C-15 On Manufactured Masonry Units		424.33
Committee C-18 On Natural Building Stones		342.58
Committee D-1 On Paint, Varnish, Lacquer and Related Products		835.22
Committee D-2 On Petroleum Products and Lubricants		186.48
Committee D-2 ASTM-IBM		923.79
Committee D-2 D.C.C Reference Fuel Account		27 516.15
Committee D-2 D.C.C National Exchange Group		−323.66
Committee D-2 D.C.C Equipment Development Project		848.70
Committee D-4 On Road and Paving Materials		809.24
Committee D-5 On Coal and Coke		233.06
Committee D-7 On Wood		39.50
Committee D-7 Wood Pole Research Fund		10 400.81
Committee D-9 On Electrical Insulating Materials		2 405.37
Committee D-10 On Shipping Containers		59.05
Committee D-11 On Rubber and Rubber-like Materials		81.75
Committee D-12 On Soaps and Detergents		750.38
Committee D-13 On Textile Materials		1 529.22
Committee D-15 On Engine Antifreezes		43.00
Committee D-18 On Soil Testing Procedures		76.00
Committee D-19 On Industrial Water—Max Hecht Award Fund		122.60
Committee E-3 On Chemical Analysis of Metals		146.54
Committee E-4 On Metallography		2.50
Committee E-9 On Fatigue of Metals		214.31
Committee E-14 On Mass Spectrometry		763.65
ASA Sectional Committee on Specifications for Cast Iron Pipe		1 377.69
Cleveland District Council		632.59
Detroit District Council		2 588.61
Ohio Valley District Council		4.50
Philadelphia District Council		319.73
Philadelphia District Special (Annual Meeting Account)		807.42
Southern California District Council		201.70
Pittsburgh District Council		576.56
Western New York—Ontario District Council		220.68
Advisory Committee on Corrosion		62 975.74
Administrative Committee on Ultimate Consumer Goods		218.30
Joint Committee on X-ray Diffraction, chemical analysis		20 538.58
Joint Committee on X-ray Diffraction, research associates		7 360.11
Joint Committee on X-ray Diffraction, IBM calculator		100.00
		159 769.00
Accounted for as follows:		
Cash in bank and on hand	$125 844.00	
Investments (at cost)	33 925.00	$159 769.00

DUDLEY MEDAL AND MARBURG LECTURE FUND

Balance, December 11, 1953:			
Principal—Investments (at cost)	$6 625.00		
Income—Cash	1 131.01	$7 756.01	
Receipts—Interest on investments		396.00	$8 152.01
Disbursements:			
Honorarium		400.00	
Dudley Medal		77.70	
Miscellaneous (travel expense, etc.)		152.75	630.45
Balance, December 10, 1954:			7 521.56
Accounted for as follows:			
Principal—Investments (at cost)		6 625.00	
Income—Cash in bank		896.56	$7 521.56

RICHARD L. TEMPLIN AWARD FUND

	Total	*Invested*	*Uninvested Cash*
Principal Account:			
Balance, December 11, 1953	$1 669.14	$1 057.20	$611.94
Receipts:			
Transfer from income—stock dividend	31.29	31.29	
Donation of R. L. Templin	400.00		400.00
	$2 100.43	$1 088.49	$1 011.94
Income Account:			
Balance, December 11, 1953		$88.24	
Receipts—Interest and dividends on investments		65.65	$153.89
Disbursements:			
Transfer to principal account		31.29	
Templin Awards		50.00	
Engrossing certificates		2.50	83.79
Balance, December 10, 1954			$70.10

SAM TOUR AWARD FUND

	Total	*Invested*	*Uninvested Cash*
Principal Account:			
Balance, December 11, 1953	$1 569.58	$1 569.58	
Receipts—Transfer from income account	31.29	31.29	
	$1 600.87	$1 600.87	
Income Account:			
Balance, December 11, 1953		$142.99	
Receipts—Interest and dividends on investments		97.10	$240.09
Disbursements:			
Transfer to principal account		31.29	
Award		35.00	
Engrossing certificate		1.25	67.54
Balance, December 10, 1954			$172.55

ASTM RESEARCH FUND

	Total	*Invested*	*Uninvested Cash*
Principal Account:			
Balance, December 11, 1953	$57 030.05	$53 995.66	$3 034.39
Receipts—Transfer from income account	3 200.00		3 200.00
Stock dividends transferred from income	187.74	187.74	
Bequest—C. L. Warwick	500.00		500.00
Bequest—H. J. Love	7 271.90	2 115.00	5 156.90
Contribution from General Fund	3 000.00		3 000.00
Bond matured		−3 000.00	3 000.00
Purchase of securities		9 715.86	−9 715.86
	$71 189.69	$63 014.26	$8 175.43
Income Account:			
Balance, December 11, 1953		$5 783.19	
Receipts—Interest and dividends on investments		2 958.16	$8 741.35
Disbursements:			
Transfers to principal account		3 387.74	
Printing, etc.		1 101.36	4 489.10
Balance, December 10, 1954			$4 252.
			5

F. E. RICHART AWARD FUND

	Total	*Invested*	*Uninvested Cash*
Principal Account:			
Balance, December 11, 1953		0	
Receipts—Contributions		$1 000.00	
Disbursements:			
None			
			$1 000.00
Income Account:			
Balance, December 11, 1953		0	
Receipts:			
Interest on savings account		$ 10.70	
Contribution from general funds		100.00	$110.70
Disbursements:			
Award			100.00
Balance, December 10, 1954			$10.70

RECEIPTS AND DISBURSEMENTS

FOR THE PERIOD DECEMBER 11, 1953 TO DECEMBER 10, 1954

Cash balance, December 11, 1953			$101 212.48

RECEIPTS

Operating Receipts (Budgeted):			
Dues and Entrance Fees:			
Current Dues	$225 181.44		
Past Dues	1 154.28		
Advance Dues	5 762.85		
Income, Life Membership Fund	175.00		
Entrance Fees	4 072.00		
Total Dues		$236 345.57	
Sales of Publications:			
Book of Standards (Members, additional parts)	54 916.50		
Back Book of Standards and Supplements	135.76		
1952 Book of Standards	92 642.85		
1953 Supplements to Book of Standards	57 683.69		
1954 Supplements to Book of Standards	1 153.70		
Methods of Chemical Analysis of Metals	3 341.88		
Compilation of Standards	75 383.06		
Separate Standards	30 951.83		
Selected Standards for Students	4 486.20		
Proceedings	7 352.25		
50-Year Index and Papers	747.15		
BULLETIN Subscriptions (nonmembers)	3 353.56		
Special and Miscellaneous Publications	138 310.43		
Total Sales of Publications		470 458.86	
Miscellaneous:			
Advertising—BULLETIN	26 268.91		
Advertising—Index	1 945.00		
Interest and Dividends	23 753.97		
Registration and Other Fees—Meetings	12 580.91		
ASTM Exhibit at Annual Meeting	16 144.27		
Staff Services	6 563.69		
Miscellaneous	484.32		
Total Miscellaneous Items		87 741.07	
Total Operating Receipts (Budgeted)		794 545.50	
Nonoperating Receipts (Not Budgeted):			
Investments Matured or Sold	37 219.38		
Excess Remittance	2 393.54		
Committee C-1 for Technical Assistant	2 640.00		
Retirement Fund Reserve	242.25		
Joint AIME-ASTM Publication Fund	50.75		
Sale of X-ray Diffraction Cards	64 432.35		
British and IP Metric Tables	2 584.91		
Institute of Petroleum Publications	305.36		
From Building Fund on Account of Loan	8 700.00		
Annual Meeting Dinner	2 400.00		
Annual Meeting Luncheons and Buffet Supper	1 164.50		
H. J. Love Fund	5 227.40		
Repayment from Committee D-7	5 000.00		
Gillett Memorial	401.25		
Warwick Memorial	513.93		
Miscellaneous	222.88		
Total Nonoperating Receipts		133 498.50	
Total Receipts			928 044.00
Total Receipts for 1954 and Cash Balance, December 11, 1953			**$1 029 256.48**

DISBURSEMENTS

Operating Disbursements (Budgeted):

Publications:			
Year Book	$14 667.79		
1952 Book of Standards	3 157.30		
1955 Book of Standards	38.88		
1953 Supplements to Book of Standards	4 331.15		
1954 Supplements to Book of Standards	45 128.34		
Methods of Chemical Analysis of Metals	149.28		
Compilation of Standards	30 509.57		
Separate Standards	13 504.69		
Proceedings—repurchase of old numbers	146.50		
1953 Proceedings	−5 558.81		
1954 Proceedings	41 667.55[a]		
Preprints	10 042.74		
ASTM BULLETIN	35 590.16		
Circulars to members	2 331.33		
Index to Standards	8 356.02		
Special and Miscellaneous Publications	73 283.30		
Total Disbursements—Publications		$277 345.79	
Salaries	276 855.47		
General Office Expenses	79 801.86		
Expenses—Technical and District Committees	11 170.67		
Expenses—Meetings	22 098.98		
Headquarters Occupancy Expense (includes $7 450 depreciation on building)	31 034.70		
American Standards Association	1 500.00		
Traveling Expense, Administrative and Special Committees	6 722.75		
Furniture and Fixtures	11 110.04		
Principal ASTM Research Fund	3 000.00		
Dues, Contributions, Miscellaneous	1 668.57		
Legal Services	1 250.00		
Group Insurance	767.04		
Employees' Retirement Fund	21 664.41		
Federal Old Age Survivors	4 092.58		
Blue Cross	904.65	473 641.72	
Total Operating Disbursements (Budgeted)		750 987.51	

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[a] These accounts include $68 500 representing a check drawn against cost of 1954 Proceedings and 1954 Supplements to Book of Standards, but not actually paid on December 9, 1954.

Nonoperating Disbursements (Not Budgeted):

Refund of Excess Remittances	2 400.04		
Investments	91 270.64		
Technical Assistant Committee C-1	2 659.20		
Transfer to Joint Committee on X-ray Diffraction	15 000.00		
Cost and Refunds on X-ray Diffraction Cards	13 865.85		
Institute of Petroleum Publications	2 354.04		
Annual Meeting Dinner	2 572.50		
Annual Meeting Luncheon and Buffet Supper	1 446.90		
Executive Retirement Reserve	900.00		
Gillett Memorial Fund	516.00		
Warwick Memorial	2 577.86		
Insurance—Corrosion Test Site	335.55		
Contribution to Medal and Lecture Fund	100.00		
Commercial Directory	229.10		
New Kinametic Miscellaneous Index	1 183.27		
H. J. Love Fund	5 227.40		
Gift to Widow of Executive Secretary	5 000.00		
Miscellaneous	286.00		
Total Nonoperating Disbursements		147 924.35	
Total Disbursements			898 911.86
Cash Balance, December 10, 1954			$130 344.62

ASTM BUILDING FUND

DETAILS OF ASTM BUILDING FUND CASH RECEIPTS AND DISBURSEMENTS FOR THE PERIOD DECEMBER 11, 1953 TO DECEMBER 10, 1954

Cash balance, December 11, 1953			$63 601.49
Receipts			
Contributions from Members		$2 041.14	
Interest and Dividends on Investments		1 036.73	
From ASTM General Fund:			
On Account of Depreciation on Building, Elevator, and Air Conditioning Installation		7 450.00	
On Account of Amortization of Note		8 700.00	19 227.87
			82 829.36
Disbursements			
Expenses of Cherry St. Property:			
Real Estate Taxes	$1 509.48		
Water and Sewer Rent	126.23		
Other Expense (Net of Rents Recieved)	113.41	1 749.12	
Renovation Cost of 1925–1929 Cherry St.:			
Contractor	53 312.74		
Air Conditioning Units	3 411.76		
Plumbing	251.65		
Electrical	757.39		
Photos	63.25		
Blueprints	14.22	57 811.01	
Cost of Moving Offices to 1925–1929 Cherry St.		1 309.69	
Reduction of Loan from ASTM General Fund		8 700.00	69 569.82
Cash balance, December 10, 1954			$13 259.54

ASTM BUILDING FUND

DETAILS OF ASSETS AND LIABILITIES OF BUILDING FUND AS OF DECEMBER 10, 1954

Assets

Cash in Girard Trust Corn Exchange Bank, Philadelphia, Pa.				$13 259.54
Investments: (Market value $13 165.94)				
$8 500 U. S. Treasury bonds 2½s 1967–72			$8 632.83	
5 000 U. S. Savings bonds series "G" 2½s			5 000.00	13 632.83
Property 1916–1918 Race St., Philadelphia, Pa:				
Cost:				
Land			30 000.00	
Building		$26 503.35		
Construction (Net of Salvage)	$129 887.52			
Electrical fixtures – 1954	757.39	130 644.91		
		157 148.26		
Accumulated Depreciation (Provided from General Funds)		42 850.00	114 298.26	
			144 298.26	
Property 1921–1929 Cherry St., and 1924–1930 Quarry St., Philadelphia, Pa:				
Cost:				
Land		38 500.00		
Buildings (Net of Income)	$48 520.29			
Construction	57 053.62			
	105 573.91			
Accumulated Depreciation (Provided from General Funds)	1 750.00	103 823.91	142 323.91	
Property 1919 Cherry St., Philadelphia, Pa:				
Cost		7 659.42		
Improvements		890.47	8 549.89	295 172.06
Total assets				322 064.43

Liabilities and Funds

Contributions from Members			$175 763.49	
Contributions from ASTM Funds			56 689.57	
Accumulated Income:				
Interest and Dividends on Investments		$6 242.41		
Profit on Disposal of Securities, net		76.27		
Profit on Sale of 1915–1919 Cherry St.		13 148.52		
Rental on Cherry St. Property		699.09		
		20 166.29		
Less Heating of Cherry St. Property	$812.50			
Interest on Loan from General Fund	4 010.96			
Real Estate Taxes on Cherry St.	2 545.66			
Water and Sewerage on Cherry St.	126.23			
Moving Expense	1 309.69			
Appraisal	150.00	8 955.04	11 211.25	
Loan Payable to ASTM General Funds			78 400.12	$322 064.43

INVESTMENTS

AS OF DECEMBER 10, 1954

GENERAL FUNDS

Par Value	*Bonds*	*Cost or Book Value*	*Market Value*[a]
$5 000	American Tobacco Debs. 3s 1969	$5 067.08	$5 018.50
4 000	Erie R. R. Co. Gen. Conv. Income "A" 4½s 1/1/2015	2 832.00	3 150.00
3 000	Pacific Gas & Electric Co. 1st Pref. Mtg. Series "W" 3⅛s 1984	3 090.57	3 063.75
5 000	Southern Natural Gas Co. 1st Mtg. SF 3⅛s 1974	5 109.81	5 050.00
30 600	U. S. Savings Bonds Series "G" 2½s	30 600.00	29 371.20
2 000	U. S. Treasury 3¼s 6/15/83–78	2 000.00	2 200.00
15 000	U. S. Treasury 2½s 11/15/61	15 000.00	15 150.00
15 000	U. S. Treasury 2½s 8/15/63	14 943.75	15 070.31
5 000	Walworth Co. 3¼s Conv. Debs. 5/1/76	5 496.53	3 550.00
		$84 139.74	$81 623.76

Shares	*Preferred Stocks*		
30	Allegheny Ludlum Steel Corp. $4.375 Cum. Conv.	$3 037.34	$3 360.00
67	American Airlines, Inc. 3½s Cum. Conv.	5 911.55	7 018.25
10	American Cyanamid Co. 3¾% "C" Cum. Conv.	1 019.75	1 127.50
30	Armstrong Cork Co. 3.75% Cum. "A"	2 947.09	3 056.25
50	Chicago, Rock Island & Pacific R. R. Co. "A"	4 434.60	5 225.00
30	Consolidated Edison Co. of N. Y. $5 Cum.	3 286.08	3 285.00
30	Endicott Johnson 4% Cum.	2 937.50	3 015.00
50	Food Machinery and Chemical Co. 3¼% Cum. Conv.	4 750.10	5 350.00
60	Jones & Laughlin Steel Corp. 5% Cum. "A"	5 386.73	5 760.00
30	Long Island Lighting Co. 4.35% Cum. "E"	3 015.00	3 097.50
30	P. Lorillard Co. 7% Cum.	4 380.00	4 350.00
30	Mississippi Power & Light 4.36% Cum.	3 075.00	3 090.00
30	Philadelphia Electric Co. 4.40% Cum.	3 285.00	3 345.00
30	Westinghouse Electric Corp. 3.80% Cum. "B"	3 067.74	3 082.50
		$50 533.48	$54 162.00

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[a] **Market values were taken from current financial publications as of close of market December 10, 1954.**

Shares	*Common Stocks*	*Cost or Book Value*	*Market Value*[a]
150	Allis-Chalmers Mfg. Co.	$6 391.35	$10 762.50
125	Aluminum Co. of America	4 820.70	10 750.00
100	American Cyanamid Co.	3 669.14	5 087.50
100	American Rad & Std. Sanitary Corp.	1 564.32	2 250.00
50	American Telephone & Telegraph Co.	8 031.72	8 768.75
100	American Tobacco Co.	7 370.97	6 362.50
30	Atchison, Topeka & Santa Fe Rwy. Co.	2 961.06	3 885.00
40	Bethlehem Steel Co.	2 095.99	3 800.00
115	Carpenter Steel Co.	6 104.75	6 583.75
100	Chase National Bank	3 412.50	5 500.00
55	Climax Molybdenum	2 302.61	3 066.25
1	Consumers Power	37.00	47.38
50	Crown Zellerbach Corp.	1 484.79	2 962.50
17	Delaware Power & Light Co.	283.00	554.63
160	Dow Chemical Co.	3 944.32	7 020.00
30	E. I. du Pont de Nemours & Co.	2 899.12	4 987.50
75	General Electric Co.	1 801.50	3 421.88
150	General Telephone Corp.	3 312.82	5 381.25
25	B. F. Goodrich	1 647.31	2 975.00
224	Gulf Oil Corp.	6 273.27	14 112.00
120	Houston Lighting & Power Co.	3 671.11	4 575.00
200	International Harvester Co.	6 406.67	7 100.00
100	International Nickel Co. of Canada	3 933.70	5 675.00
50	Johns-Manville Corp.	3 433.25	4 312.50
200	Lone Star Cement Co.	4 941.44	11 675.00
45	Montgomery, Ward & Co.	2 646.41	3 459.38
3	Niagara Mohawk Power Co.	83.82	93.75
100	Ohio Oil Co.	2 623.35	6 837.50
57	Pacific Gas & Electric Co.	2 165.63	2 572.13
50	Parke Davis & Co.	1 641.19	1 781.25
50	Pennsylvania Power & Light Co.	2 083.20	2 218.75
50	Chas. Pfizer & Co.	1 732.94	1 750.00
271	Philadelphia Electric Co.	6 630.01	10 365.75
125	Public Service Electric & Gas Co.	4 558.50	3 593.75
50	Republic Steel Corp.	2 152.93	3 481.25
50	Sears, Roebuck & Co.	3 137.78	3 787.50
100	Socony-Vacuum Oil Co.	2 510.28	4 887.50
50	Southern Pacific Co.	2 234.45	2 593.75
40	Standard Oil Co. of New Jersey	2 835.61	4 380.00
40	Texas Co.	2 184.35	3 440.00
60	Union Carbide and Carbon Co.	4 235.24	5 122.50
25	Union Pacific Railroad Co.	2 719.78	3 656.25
30	United Gas Improvement Co.	446.68	1 080.00
65	Westinghouse Electric Corp.	3 890.72	4 988.75
		$143 307.28	$211 705.65

Shares	*Mutual Funds*		
271	Broad Street Investing Corp.	$5 375.04	$7 625.94
3 701.098	Commonwealth Investment Co.	26 000.28	30 237.97
4 262	Eaton & Howard Balanced Fund	64 363.27	80 466.56
2 022	Fundamental Investors, Inc.	18 269.34	26 063.58
		$114 007.93	$144 394.05

ASTM BUILDING FUND

Par Value	*Bonds*		
$8 500	U. S. Treasury 2½s 6/15/72–67	$8 632.83	$8 430.94
5 000	U. S. Savings Bonds series "G" 2½s	5 000.00	4 735.00
		$13 632.83	$13 165.94

ASTM RESEARCH FUND

Par Value	*Bonds*	*Cost or Book Value*	*Market Value*[a]
$1 500	B. &. O. R. R. Ref. & Gen. 5s series "M" 3/1/96	$1 511.25	$1 380.00
2 000	Pacific Gas & Light Co. 3⅛s 1984	2 060.21	2 042.50
4 000	Socony-Vacuum Oil Co. 2½s 1976	3 899.85	3 810.00
6 900	U. S. Defense Savings Bonds series "G" 2½s	6 900.00	6 628.80
2 000	U. S. Treasury 2½s 3/15/70–65	2 000.00	1 985.63
		$16 371.31	$15 846.93

Shares	*Preferred Stocks*		
33	American Airlines, Inc. 3½s Cum. Conv.	$3 366.00	$3 456.75
30	General Motors $5 Cum.	3 755.80	3 761.25
47	Standard Slag Co. 2nd Pfd.	2 115.00	2 115.00
		$9 236.80	$9 333.00

Shares	*Common Stocks*		
160	Allis-Chalmers Mfg. Co.	$7 428.81	$11 480.00
196	General Motors Corp.—Gift[b]	6 504.75	17 885.00
100	Jones & Laughlin Steel Corp.	2 636.06	3 000.00
55	Montgomery, Ward & Co.	3 151.63	4 228.13
		$19 721.25	$36 593.13

Shares	*Mutual Funds*		
295	Broad Street Investing Corp.	$5 962.83	$8 301.30
706	Eaton and Howard Balanced Fund	11 722.07	13 329.28
		$17 684.90	$21 630.58

DUDLEY MEDAL AND MARBURG LECTURE FUND

Par Value	*Bonds*		
$500	B. & O. R. R. Ref. & Gen. Mtg. 6s series "J" 12/1/95	$550.00	$503.75
6 000	B. & O. R. R. Ref. & Gen. Mtg. 5s series "G" 12/1/95	6 075.00	5 520.00
		$6 625.00	$6 023.75

RICHARD L. TEMPLIN AWARD FUND

Shares			
72	Eaton and Howard Balanced Fund	$1 088.49	$1 359.36

SAM TOUR AWARD FUND

Shares			
106	Eaton and Howard Balanced Fund	$1 600.87	$2 001.28

COMMITTEE FUNDS

Par Value			
$1 000	U. S. Treasury Bonds 2⅞s 3/15/60–55	$1 000.00	$1 005.94
2 000	U. S. Treasury Bonds 2½s 12/15/69–64	2 000.00	1 989.38
3 000	U. S. Treasury Bonds 2½s 3/15/70–65	3 000.00	2 978.44
3 000	U. S. Treasury Bonds 2½s 12/15/72–67	3 000.00	2 975.63
5 000	U. S. Savings Bonds series "G" 2½s	5 000.00	4 735.00

X-RAY DIFFRACTION COMMITTEE

Par Value			
20 000	U. S. Treasury Bonds 2½s 8/15/63	19 925.00	20 093.75
		$33 925.00	$33 778.14

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[b] The income from these shares is, by agreement, paid to an annuitant.

APPENDIX II

REPORT OF ADMINISTRATIVE COMMITTEE ON STANDARDS

The Administrative Committee on Standards, functioning broadly as it does in supervising the standardization work of the Society, is in an excellent position to appreciate how active the technical committees of the Society are in bringing in recommendations covering new standards, and more particularly in reviewing currently all of the standards and tentatives under their jurisdiction to see that these are up to date and in accord with commercial practice. It also appreciates the gaps in the Society's coverage and sees fields where work should be undertaken. The several functions are discussed under the subdivision headings of this report.

The review of recommendations from technical committees is, of course, one of the important functions of the Standards Committee, since in its establishment it was intended to provide a means of having recommendations acted upon in the interval between Annual Meetings. Most of the annual reports refer to recommendations that have been submitted to the Standards Committee during the year. The actions this year include:

New Tentatives	41
Revised Tentatives	93
Tentative Revisions of Standards	5
Standards Revised and Reverted to Tentative	8
Tentatives Withdrawn	1
Emergency Alternates Withdrawn	9

A large number of these recommendations were acted upon at meetings held on September 28, 1954, and March 23, 1955; the remainder were handled by correspondence.

Actions at 1954 Annual Meeting:

As a matter of record, the actions taken by the Society at the 1954 Annual Meeting with respect to standards and tentatives are tabulated below:

Existing Tentatives Adopted as Standard	108
Standards Revised	27
New Tentatives	65
Standards Revised and Reverted to Tentative	18
Tentative Revisions of Standards	25
Tentatives Revised	118
Standards and Tentatives Withdrawn	7

Form of Standards:

Improvement of the quality and form of standards continues to be an important consideration of the committee. Editorial committees have been organized by a number of the technical committees, and the Standards Committee would wish to see this practice extended. Manuals covering the form of ASTM methods of testing and specifications are in preparation: the one covering specifications will shortly be distributed to the officers of technical committees, and it is expected that Committee E-1 on Methods of Testing will shortly have available a companion manual on methods of testing. Many of the technical committees are greatly interested in questions of format, and those having editorial committees will especially appreciate the availability of these manuals.

EXPANSION OF STANDARDIZATION ACTIVITIES

At no time have so many proposals dealing with new projects been before the Standards Committee for development. Apart from these, however, which are referred to in detail below, the committee has been interested in noting the realignment of work on electronic materials. It is proposed to have an independent technical committee of the Society set up to handle this work which was formerly under the jurisdiction of Subcommittee VIII on Metallic Materials for Radio Tubes and Incandescent Lamps of Committee B-4.

Hydraulic Fluids.—The committee's attention has been called to the need for test procedures for synthetic hydraulic fluids. There is an ever-increasing application of such fluids, and although some standardization has been carried out as applied to the petroleum base fluids, the introduction of the synthetic-type fluids presents a need for additional tests. A conference is being called of those interested to determine the extent of interest in this field and to bring recommendations to the Board of Directors concerning the establishment or otherwise of a new committee on the subject.

Clay Absorbent Materials.—The proposal has been received that the Society undertake work in the field of clay absorbent materials, for example, fuller's earth. A conference of those interested in the subject is being arranged, possibly for the late spring or early summer. The scope of exploration will include the diatomaceous materials as well, since some of these are also used as absorbent materials.

Manganese Dioxide, Carbon Black.—The attention of the Administrative Committee on Standards has been called to the need for standards covering manganese dioxide for use in dry batteries. A group is already at work in this field, and inquiry has been made as to whether provision could be made under the Society's jurisdiction for this work. Carbon black has also been mentioned in this connection, and separate inquiries with respect to carbon black have been received. In view of the many uses of carbon black and its interest to a number of ASTM committees, presumably this subject should be developed separately. It is interesting to note in this connection that Committee D-11 on Rubber and Rubber-like Materials is now considering the extension of its scope to include fillers and reinforcement materials.

Leather.—While discussion has taken place on various occasions in the past with respect to the Society's undertaking work on leather, no specific action has ever been taken toward organizing a committee on the subject. Discussions are now taking place with the American Leather Chemists Assn., having in mind the possibility of setting up a joint committee with that organization to deal with the physical testing of leather.

Casein.—Consideration is now being given to a proposal that the Society undertake work on casein as such. Committee D-14 on Adhesives is particularly interested, but since casein is also used in other applications already covered by committees of the Society—for example, Committee D-1 on Paint and Committee D-6 on Paper—these committees would also be involved. A group especially interested in casein proposes to hold a meeting shortly at which time this subject of setting up work independently of these other committees could be explored.

Caulking Compounds.—In the report a year ago, reference was made to the need for work on caulking compounds. Committee D-1 has organized a subcommittee on putty, caulking compounds, and similar materials.

Gasket Materials.—The Standards Committee still has under consideration the question of the expansion of the Society's work on gaskets. A number of nonmetallic materials are now covered in the standards prepared under Committee D-11 on Rubber and Rubber-like Materials, some of the work having originated in the Joint SAE-ASTM Technical Committee on Automotive Rubber. In view of the current interest in metallic gasketing materials as well as the various combinations, there is some feeling that the work should be established in a separate committee, and this question is being explored, although generally it has been the policy to look to existing committees in the assignment of new work whenever this is practicable.

Investment Castings.—There has been brought to the attention of the administrative committee the possible need for organized work with respect to investment castings. Some work has already been initiated in one or more of the Society's metals committees, and this may need coordination.

Industrial Chemicals.—The subject of industrial chemicals is so broad that a preliminary conference should first be held to delineate the field more specifically. A number of projects undertaken during recent years, either in new committees or by existing technical committees, covers certain portions of this general field, so it would be well to determine more definitely what is still needed.

Cooperative Relations.—To an ever increasing extent, there is an interlocking of interest among the technical committees, particularly in the nonmetallic field. More recently the question has developed as to how the Society might best handle the subject of foamed plastics. Committee D-11 has been quite active in dealing with the rubber-like foams, whereas a number of committees are interested in various applications of the rigid plastic foams. It is proposed that a coordinating committee be set up to include representation from the various committees concerned.

RELATIONS WITH AMERICAN STANDARDS ASSOCIATION

Two methods under the procedure of the American Standards Assn. are used by ASTM in submitting recommendations to the ASA. One is a combination of the so-called existing standards procedure and the proprietary sponsorship procedure. On the initial reference of an existing ASTM standard to the ASA, it is submitted under the existing standards procedure with a supporting statement giving a history of the development of the standard and indicating the degree of its acceptance. If the standard is approved as American Standard, the ASTM is granted proprietary sponsorship insofar as any future revisions are concerned, and such revisions are brought to the attention of the ASA currently for approval under this proprietary sponsorship procedure.

The second method consists of having standards reviewed in a sectional committee made up of representatives of a number of interested organizations usually with the ASTM as sponsor or cosponsor of the sectional committee.

Standards Submitted Under the Existing Standards Procedure:

The following standards were submitted to the American Standards Assn. for approval as American Standard under the existing standards procedure: 12 standards dealing with bituminous dampproofing and waterproofing (D 41, D 146, D 173, D 226, D 227, D 250, D 255, D 450, D 451, D 452, D 654, D 655).

Revised Standards Submitted Under the Proprietary Procedure:

In view of the Society's having been designated as proprietary sponsor for the revisions of ASTM standards that have been approved as American Standard under the existing standards procedure, it has submitted to the American Standards Assn. during the year revisions of 7 standards relating to copper and copper alloys (B 42, B 43, B 88, B 99, B 100, B 124, B 140), revisions of 1 dealing with gypsum wallboard (C 36), 1 relating to the physical testing of rubber products (D 15), and 1 relating to sampling and chemical analysis of alkaline detergents (D 501).

Standards Submitted Under Sectional Committee Procedure:

During the year, the following two sectional committees, for which the Society is sponsor, took action to present recommendations to the ASA as follows:

Sectional Committee C59 on Electrical Insulating Materials.—This committee has recommended the approval as American Standard of 1 ASTM specification and the approval of revisions of 4 American Standards.

Sectional Committee Z11 on Petroleum Products and Lubricants.—This committee has recommended the approval as American Standard of 1 ASTM method and the approval of revisions of 7 American Standards.

These reports have been referred to the American Standards Assn. Action is still pending so far as the recommendations of Sectional Committee C59 are concerned; the report of Sectional Committee Z11 has been approved.

INTERNATIONAL RELATIONS

The Society continues to receive from other countries standards with the request for comment. ASTM committees review these standards, and frequently suggestions result. Apart from such informal cooperation, however, quite a number of proposals have been received through the American Standards Assn. concerning projects that have been organized under the International Organization for Standardization (ISO) as follows:

Textiles.—Great Britain holds the general secretariat for ISO/TC 38 on Textiles, but the United States holds the secretariat for several subcommittees. American participation in this work of ISO/TC 38 is being handled by a special committee organized under the sponsorship of ASTM and the American Association of Textile Chemists and Colorists, with representation from the various groups interested. This special committee has been given the designation "L23."

This ISO committee has worked on the following items: drafting of textile standards, analysis of fiber mixtures, moisture in textile materials, definitions and nomenclature, methods of measurement of cloth, colorfastness tests, shrinkage of fabrics in washing, systematic reduction in the number of yarn counts, yarn testing, fiber testing, and ropes and cordage.

A meeting of the subcommittee on ropes and cordages is scheduled for July 5 to 7, 1955, in Brussels, Belgium.

Petroleum Products.—America holds the secretariat for ISO/TC 28 on Petroleum Products, the technical work of the secretariat being under the purview of Sectional Committee Z11, for which ASTM is sponsor.

A meeting of ISO/TC 28 is scheduled for June 23 to 24, 1955, in London, England, and a number of delegates from the United States will attend.

Rubber.—The secretariat for ISO/TC 45 on Rubber is held by Great Britain. The American group to handle participation in this ISO committee has been set up under ASTM Committee D-11 with R. D. Stiehler, chairman. A number of draft proposals are under consideration, and a further meeting of ISO/TC 45 is scheduled for September 5 to 9, 1955, in Düsseldorf, Germany.

Viscosity.—America holds the secretariat for ISO/TC 66 on Viscosity. The Subcommittee on Rheological Properties of ASTM Committee E-1 has been set up to handle the work of the secretariat.

Plastics.—America holds the secretariat for ISO/TC 61 on Plastics. ASTM Committee D-20 is handling the work of the secretariat and has organized for the purpose a special committee consisting of representatives of the various groups interested.

A meeting of ISO/TC 61 is being held in Paris, France, July 8 to 13, 1955, at which it is expected the United States will have a number of delegates.

Shellac.—Subcommittee XIII on Shellac of ASTM Committee D-1 has been set up as the American committee in charge of contacts with ISO/TC 50 on Lac for which India holds the secretariat. America has submitted a number of comments with respect to standards dealing with shellac that are now under consideration.

Solid Mineral Fuels.—ASTM Committee D-5 is handling the United States contacts with ISO/TC 27 on Solid Mineral Fuels. A meeting of this ISO committee is scheduled for June, 1955, in Stockholm, Sweden, at which America will be represented by W. A. Selvig, U. S. Bureau of Mines, and O. W. Rees, Illinois State Geological Survey.

Iron and Steel.—The United States has the status of an observer in connection with the work of ISO/TC 17 on Iron and Steel, for which the British hold the secretariat. A number of draft proposals have been received which have been brought to the attention of Committee A-1 on Steel, while others dealing with methods of testing have been submitted to the appropriate subcommittees of Committee E-1.

A meeting of ISO/TC 17 is planned for June 6 to 11, 1955, in Stockholm, Sweden.

Chemicals.—Several ASTM committees have indicated an interest in the work of ISO/TC 47 on Chemicals, and draft proposals have been received which have been passed on to the committees.

Laboratory Glassware.—Committee E-1 has indicated that it favors active American participation in the work of ISO/TC 48.

Statistical Treatment of Series of Observations.—Committee E-11 favors American participation in the work of ISO/TC 69. This recommendation is concurred in by the American Society for Quality Control, American Statistical Assn., and Institute of Mathematical Statistics.

Mica.—Subcommittee IX on Mica of ASTM Committee D-9 has been set up to handle the American contacts with ISO/TC 56 for which India holds the secretariat. The subcommittee has submitted comments with respect to standards dealing with mica that are now under consideration.

Copper and Copper Alloys.—The Advisory Committee of ASTM Committee B-5 has been set up to handle the work of the secretariat for ISO/TC 26 on Copper and Copper Alloys. An organization meeting of this committee is being held this June.

Paper.—On the recommendation of ASTM Committee D-6, America participates in the work of ISO/TC 6 on the basis of an observer. Copies of all proposals are received and referred to Committee D-6 for its information.

Timber.—ASTM Committee D-7 on Wood has indicated that it favors American participation in the work of ISO/TC 55 on Timber.

Raw Materials for Paints, Varnishes, and Similar Products.—ASTM Committee D-1 has indicated that it favors American participation in the work of ISO/TC 35.

Asbestos-Cement Products.—ASTM Committee C-17 on Asbestos-Cement Products has indicated that it favors American participation in the work of ISO/TC 77 on the basis of an observer.

Light Metals and Their Alloys.—ASTM Committee B-7 has indicated that it favors American participation in the work of ISO/TC 79.

Refractories.—ASTM Committee C-8 has indicated that it favors American participation in the work of ISO/TC 33.

Respectfully submitted on behalf of the committee,

J. H. FOOTE,
Chairman.

R. E. HESS,
Secretary.

APPENDIX III

REPORT OF ADMINISTRATIVE COMMITTEE ON RESEARCH

A meeting of the Administrative Committee on Research was held November 15, 1954. Aside from continuing activities initiated in the past, some new steps were taken which, it is believed, will aid substantially in promoting increased research activity and knowledge of the Society's progress in obtaining new information on engineering materials.

The committee has plans to sponsor a session or symposium on current research work at the Annual Meetings, beginning in 1956. To reduce current progress by the various ASTM committees into a form that it is hoped will attract wider interest, the ACR is promoting publication of a series of "popular" articles in the BULLETIN. They would cover recent progress in specific fields of ASTM activity in a way that would be informative without being burdened with too much detail. Each member of the committee will be responsible for "ACR Notes" for one issue of the BULLETIN a year.

The ACR has suggested that a paragraph on research be included in the annual reports of technical committees. Research activities should be of sufficient importance to segregate such items into a separate section of the report where it can receive deserved attention.

A "Review of ASTM Research" is published periodically by the committee. It is planned that this be issued every two years to acquaint the Society membership and others with the research work of the Society.

Special attention has been given to the status of technical committee research projects that involve solicitation of funds. Six such projects are now under way. Likewise, consideration has been given to cooperation of ASTM with other research groups—Governmental, the International Union of Testing and Research Laboratories for Materials and Structures, and the Engineering Foundation's "Corrosion Research Council."

Revised listings of "Some Unsolved Problems" and their distribution have been continued. Some 1800 copies of the last compilation have been requested by organizations and individuals in the United States and many foreign countries. The attention of various ASTM technical committees is being called to certain problems of probable interest listed in the National Inventors Council pamphlet, "Technical Problems Affecting National Defense."

In regard to financing new research, current expenditures and normal requests for funds, as gaged by the experience of the last few years, can be met from the Income Account. The Principal Account as of October 23, 1954, totaled $60,917.79. There was bequeathed from the estate of H. J. Love $7271.90, and an allocation has been made of $3000 from the general funds of the Society (entrance fees). The balance as of May 1, 1955, was $71,189.69. The balance in the Income Account as of October 23, 1954, was $3546.43; interest to April 30, 1955, was $1911.34. From this total of $5457.77 there were expenses of $362.70, leaving a cash balance in the Income Account as of May 1, 1955, of $5095.07. The committee feels that it cannot undertake broad researches, and it is impractical to build up a big research program. Rather, the present objective is to catalyze, stimulate, and publicize research in the Society's many divisions.

Respectfully submitted on behalf of the committee,

BRUCE W. GONSER,
Chairman.

J. S. PETTIBONE,
Secretary.

APPENDIX IV

REPORT OF ADMINISTRATIVE COMMITTEE ON PAPERS AND PUBLICATIONS

The Administrative Committee on Papers and Publications has now caught up on the backlog of material awaiting publication. This does not mean that there are no further publications, but that all of the publication work resulting from the 1954 Annual Meeting has been completed. The *Proceedings* have been distributed, and all of the special technical publications resulting from the symposiums presented at the 1954 Annual Meeting are available or in press. The Supplements to the Book of Standards, complete with the combined Index to Standards, have also been distributed.

The committee, however, always has various publication matters before it. At the present time, there is pending a very extensive publication on Significance of Tests of Concrete and Concrete Aggregates, and work on this is in progress. There are also several bibliographies submitted by individual technical committees. Committee D-2 on Petroleum Products and Lubricants has submitted a manuscript on Motor Research Methods for Rating Fuels. There is also an extensive glossary of terms of interest to the rubber industry.

1955 Book of Standards:

It is particularly fortunate that progress has been made on publication of the backlog of material that has been pending for the past few years, for the committee is now faced with one of its largest publication undertakings—the printing of the 1955 Book of ASTM Standards. The book will again appear in seven parts, although two of them will be approaching the maximum that can be handled by regular binding methods. Bible stock will again be used in order to save space. An approved type of Bible stock has been secured which will be somewhat more substantial and yet not increase the bulk materially. The press work alone for these seven parts creates a considerable problem for the printer, and special arrangements are being made to have at least one of the parts handled by a printer other than our regular one. As a convenience in the use of the standards, it is proposed to print the table of contents in numeric sequence on colored stock; other innovations are also planned.

Size of Publications:

After very careful study of a proposal that the size of publications be changed from 6 by 9 in. to $8\frac{1}{2}$ by 11 in., including a canvass of the Society's technical committees, it was concluded that the 6 by 9-in. size should be retained for regular publications but that separate standards should be made available in $8\frac{1}{2}$ by 11-in. size should there be a demand for this size in the industry concerned.

Radiographic Standards for Welds:

A publication project of a special nature is that of reference radiographs for the inspection of welds. This is another one of a series which the Society has issued which already includes steel castings and aluminum magnesium castings.

Presentation of Papers:

For the past two years, an effort has been made to improve the character of the presentation of papers. A means of rating presentations has been set up which, on a trial basis, has proved successful. The rating scheme is one in which reporters at each of the sessions, by means of check marks and one word replies, complete a comprehensive statement on items usually concerned with effective presentation. From these the nature of the presentation can be judged by a reviewing committee. The scheme has already been effective in enlisting the interest of authors in making better presentations, and considerable interest has also been aroused in other quarters on the efforts that the Papers Committee is making. It is proposed to place the judging of presentations on a regular basis with possibly the recognition of outstanding presentations.

Meetings:

Two meetings of the Administrative Committee on Papers and Publications have been held during the year, one on November 22, 1954, and the other on February 15, 1955. In all, the Papers Committee reviewed and accepted for publication 202 technical papers.

Record of Publications Issued This Year

Regular Publications:

1954 *Proceedings*, 1425 pp., 8300 copies.
1954 Supplements to Book of Standards:
  Part 1, 607 pp., 11 500 copies.
  Part 2, 445 pp., 9 500 copies.
  Part 3, 412 pp., 8 000 copies.
  Part 4, 153 pp., 7 100 copies.
  Part 5, 307 pp., 7 100 copies.
  Part 6, 531 pp., 7 000 copies.
  Part 7, 291 pp., 7 200 copies.
1954 Year Book, 672 pp., 7400 copies.
1954 Index to ASTM Standards, 306 pp., 27,000 copies.
ASTM Bulletin, 8 issues (May, 1954, to April, 1955), total number of pages 792, average number of copies 11,950 (257 pages of technical papers).

A statement of the volume of the principal publications for the past four years is given below:

Publications	1951–1952 Pages	1952–1953 Pages	1953–1954 Pages	1954–1955 Pages
Proceedings	1332	1 335	1209	1425
Book of ASTM Standards	...	9 976	...	...
Supplements to Book of ASTM Standards	1916	...	2099	2746
ASTM Methods of Chemical Analysis of Metals	...	...	...	...
Index to ASTM Standards	282	300	300	306
Year Book	608	632	644	672
Special Technical Publications	1221	1606	2604	2101
Other Special Publications	16	1 182	938	46
ASTM Bulletin	716	716	724	792
Totals	6091	15 747	8518	8088

Special Compilations of Standards Published from April, 1954, to April 15, 1955:

ASTM Specifications for Steel Piping Materials (A-1), 370 pp., 3000 copies.
ASTM Standards on Wire for Electrical Conductors (B-1), 230 pp., 800 copies.
ASTM Standards on Copper and Copper Alloys (B-5), 600 pp., 1500 copies.
ASTM Standards on Cement (C-1), 255 pp., 1800 copies.
ASTM Standards on Mineral Aggregates, Concrete, and Nonbituminous Highway Materials (C-9, D-4), 352 pp., 2600 copies.
ASTM Standards on Paint, Varnish, Lacquer, and Related Products (D-1), 868 pp., 2000 copies.

ASTM Standards on Petroleum Products and Lubricants (D-2), 984 pp., 6300 copies.
ASTM Standards on Bituminous Materials for Highway Construction, Waterproofing, and Roofing (D-4, D-8), 448 pp., 1500 copies.
ASTM Standards on Coal and Coke (D-5), 163 pp., 2000 copies.
ASTM Standards on Electrical Insulating Materials (D-9), 656 pp., 1000 copies.
ASTM Standards on Rubber and Rubber-like Materials (D-11), 683 pp., 2400 copies.
ASTM Standards on Textile Materials (D-13), 728 pp., 1800 copies.
ASTM Standards on Adhesives (D-14), 216 pp., 1500 copies.
ASTM Standards on Plastics (D-20), 741 pp., 1600 copies.
Manual on Industrial Water (D-19) (STP 148-A), 422 pp., 2000 copies.

Special Compilations in Prospect:

ASTM Standards on Glass and Glass Products (C-14), 136 pp., 1000 copies.
ASTM Standards in Building Codes, 972 pp., 2700 copies.

Special Publications Issued:

Summary of Proceedings of the Fifty-seventh Annual Meeting, 32 pp., 7600 copies.
1954 Marburg Lecture, "Interpretation of Engineering Data: Some Observations," by H. F. Dodge, 40 pp., 3000 copies.
1954 Gillett Lecture, "Fatigue of Aluminum," by R. L. Templin, 63 pp., 4500 copies.
Supplement to Symposium on Lateral Tests on Piles (STP 154-A), 48 pp., 2000 copies.
Symposium on Dynamic Testing of Soils (STP 156), 267 pp., 2000 copies.
Symposium on Effect of Temperature on the Brittle Behavior of Metals with Particular Reference to Low Temperatures (STP 158), 480 pp., 2500 copies.
Symposium on Radioactivity—An Introduction (STP 159), 50 pp., 2000 copies.
Elevated Temperature Properties of Selected Super-Strength Alloys (STP 160), 212 pp., 2500 copies.
Symposium on Temperature Stability of Electrical Insulating Materials (STP 161), 142 pp., 2500 copies.
Symposium on Odor (STP 164), 86 pp., 2000 copies.
Symposium on Effect of Cyclic Heating and Stressing on Metals at Elevated Temperatures (STP 165), 181 pp., 2000 copies.
Symposium on Diesel Fuels (STP 167), 56 pp., 2500 copies.
Bibliography of Fatigue References (STP 9-E), 34 pp., 250 copies (mimeographed).
1952–1953 Supplement to the Bibliography and Abstracts on Electrical Contacts (STP 56-H), 79 pp., 1500 copies.
1954 Supplement to the Metal Cleaning Bibliography (STP 90-C), 44 pp., 2000 copies.
Copper Strip Corrosion by Petroleum Products—1500 sets.
Supplement to ASTM Manual of Engine Test Methods for Rating Fuels, 46 pp., 3000 copies.
Reference Radiographs for Inspection of Aluminum and Magnesium Castings—50 sets.

Special Publications in Prospect:

Symposium on Coal Sampling (STP 162), 156 pp., 2000 copies.
Symposium on Permeability of Soils (STP 163), 142 pp., 2000 copies.
Symposium on Methods of Testing Building Constructions (STP 166), 138 pp., 2000 copies.
ASTM Viscosity Indices Tables Calculated from Kinematic Viscosity (STP 168), 850 pp., 3000 copies.
Significance of Tests of Concrete (STP 169), 300 pp., 3000 copies.
Chemical Compositions and Rupture Strengths of Super-Strength Alloys (STP 170), 8 pp., 2000 copies.
Symposium on Basic Effects of Environment on Strength, Scaling, and Embrittlement of Metals at Elevated Temperatures (STP 171), 150 pp., 2000 copies.
Symposium on Insulating Oils (STP 172) 60 pp., 2000 copies.
1954 Supplement to the Bibliography and Abstracts on Electrical Contacts (STP 56-I), 50 pp., 1200 copies.
Bibliographical Abstracts on Redeposition of Soil on Cotton Fabric (STP 173), 32 pp., 1500 copies.

CURRENT ACTIVITIES

The program in prospect for the 1954 Annual Meeting includes the following symposiums:

Symposium on Impact Testing.
Symposium on Speed of Testing.
Symposium on Atmospheric Corrosion of Non-Ferrous Metals.
Symposium on High-Purity Water Corrosion.
Symposium on Metallic Materials for Service at Temperatures Above 1600 F.
Panel Discussion on Pyrometry.

Respectfully submitted on behalf of the committee,

R. E. HESS,
Chairman.

APPENDIX V

REPORT OF ADMINISTRATIVE COMMITTEE ON DISTRICT ACTIVITIES

Twenty-nine ASTM district meetings, sponsored by the fourteen districts, were held during the June 1954–June 1955 year. The only district that did not hold a meeting during the year was Washington, D. C. The Chicago District Council sponsored two district meetings and in addition acted as host for the 57th Annual Meeting; this council planned the ladies' entertainment and handled details of the annual dinner, underwriting expenses and sponsoring the entertainment program.

In connection with national meetings, the Philadelphia District is arranging the ladies' entertainment and the details of the annual dinner for the Annual Meeting to be held in Atlantic City this year. The Northern and Southern California Districts have cooperated in developing a committee structure for planning and handling the details of the 1956 Second Pacific Area National Meeting to be held in Los Angeles the week of September 16, 1956.

A new approach to student membership, and one that appears to have merit, was taken at the October meeting of the Philadelphia District at which time 29 students were invited to be the guests of the Philadelphia District at a dinner meeting. In connection with the ceremonies, a certificate of "Student Membership Award" was presented. Other districts are planning to sponsor student membership awards.

President Norman L. Mochel spoke at 19 locations throughout various sections of the country. New areas not previously visited by an ASTM president included Rome, N. Y. (New York District); Bartlesville, Okla. (Southwest District); and Denver, Colo. In addition, President Mochel and Executive Secretary R. J. Painter spoke before local groups of ASTM members in Kansas City, Mo., and Portland, Ore. A number of the district meetings were sponsored solely by the local ASTM district, but the majority were cosponsored with such groups as TAPPI, ASM, Engineers' Club of St. Louis, ASME, New York State Society of Professional Engineers, SAE, American Rocket Society, Western Society of Engineers, Missouri Society of Professional Engineers, Tacoma Engineers' Club, and Pittsburgh Association of Purchasing Agents.

President Mochel's address, "Power and Materials, Now and in the Future—Some Metals and Materials Problems," was devoted primarily to the current problems created by giant new steam turbines, particularly with respect to the steadily increasing operating temperatures and pressures. This presentation was essentially the same at all locations with the exception of Detroit, where his address was modified to include references to gas turbines, especially for stationary operation. The details of the various district meetings have been recorded in various issues of the ASTM BULLETIN.

The Administrative Committee on District Activities sponsored the customary breakfast meeting for the officers of the ASTM districts with representatives present from all of the 14 districts. These breakfast meetings have proved to be quite valuable for the dissemination of ideas regarding the operation of the various ASTM districts. Items discussed at the 1954 meeting included joint meetings, the approach to make to students, stimulating the interest of inactive council members, and helping to promote interest in ASTM and ASTM membership.

A meeting of the Administrative Committee on District Activities was also held during the Annual Meeting, and a number of suggestions were discussed aimed toward facilitating the work of the various districts. It was agreed that future ballots should be modified to include suggestions for future candidates. It was also agreed that ASTM district affiliation with other engineering groups is favored, but that the districts should be cognizant of financial responsibilities and that any financial indebtedness incurred would be the responsibility of the district rather than of the Society.

In connection with each of the district meetings, printed notices were prepared and distributed to all ASTM members and committee members in a particular district, and in many cases sufficient notices were printed for distribution to other local groups. Copies of all meeting notices were sent to council members in all fourteen districts.

The ACDA has noted with interest that more meetings were sponsored this year than in any other period, attesting to the interest of the districts in fostering and promoting the work of the Society.

Respectfully submitted on behalf of the committee,

C. M. GAMBRILL,
Chairman.

APPENDIX VI

REPORT OF ADMINISTRATIVE COMMITTEE ON SIMULATED SERVICE TESTING

The Administrative Committee on Simulated Service Testing held its most recent meeting at Society Headquarters on May 5, 1955, at which time the present officers were re-elected.

The principal business of the committee was concerned with a complete review of the project list, bringing it up to date with current Society activities and those in collaboration with other organizations.

Over 30 activity items were reviewed and discussed with representatives from the Headquarters Staff. Of these items, about 20 were eliminated as being of no current interest or as being adequately covered by present activities.

Several items such as strength of adhesive bonds, dimensional changes in plastics, slipperiness of floor finishes, adherence of electrodeposited coatings, forming characteristics, etc., were recommended for referral to the appropriate technical committees for their comments or action.

Appreciable discussion centered about the desirability for suitable acceptance and evaluation tests for shot peening; the necessity for more fundamental work on fretting corrosion because of its seriousness in several aviation applications; and the desirability of macro-etch standards, this latter item to be referred to Committee E-4 for suitable action.

Respectfully submitted on behalf of the committee,

L. L. Wyman,
Chairman.

REPORT OF COMMITTEE A-1

ON

STEEL*

For several years the subject of ASTM specifications for alloy steel chain has been under consideration. In 1954, the Advisory Group of Committee A-1 authorized a new Subcommitee XXVII on Steel Chain. In a year's time the subcommittee has been organized and the personnel has developed the attached proposed Tentative Specification for Alloy Steel Chain.[1] Also under review are the Standard Specifications for Iron and Steel Chain (A 56 – 39) which have remained unchanged since 1939.

Late in 1953 the Society was informed by the ASA Sectional Committee B31 which originates the American Standard Code for Pressure Piping that the gas industry had need for a specification covering high-quality fusion welded piping 16 in. and larger in diameter for use in high-pressure gas service. After a year's intensive work in Committee A-1, the Tentative Specifications for Metal-Arc Welded Steel Pipe for High-Pressure Transmission Service (A 381 – 54 T) were accepted and published by the Society.

Another important series of actions taken during the past year was the withdrawal of Emergency Alternate Provisions permitting an increase in the phosphorus content of many of the specifications covering pipe and tubing.

Meetings.—Most of the actions submitted to the Administrative Committee on Standards during the year, as outlined in another section of this report, were approved by Committee A-1 during its meeting on June 16, 1954, in Chicago in conjunction with the 1954 Annual Meeting. On June 14 and 15, fourteen subcommittees and sections convened to prepare proposals for action by the main Committee A-1.

Several hundred of the members of Committee A-1 met on January 24, 25, and 26, 1955, in New York City, centering their activity on forgings and tubular products. Once again fourteen subcommittees met on January 24 and 25, preparing reports for the main Committee A-1 meeting on January 26. The size of the Appendix to this report and the other attached items are testimony to the activity of the committee.

Personnel.—The committee now consists of 302 voting members, including 134 producers, 125 consumers, and 43 general interest members.

Several men who distinguished themselves over many years as subcommittee chairmen resigned during the past year. The chairman of Subcommittee VIII on Steel Castings, M. V. Healey, resigned, and C. B. Jenni, General Steel Castings Corp., was appointed to this important post.

During the tenure of E. V. Bennett as chairman of Subcommittee XV on Bar Steels, the subcommittee developed many specifications, representing a complete coverage of the field. Mr. Bennett resigned during the year and was replaced by A. W. MacLaren of the U. S.

*** Presented at the Fifty-eighth Annual Meeting of the Society, June 26–July 1, 1955.**

[1] The new tentative appears in the 1955 Book of ASTM Standards, Part 1.

Steel Corp. H. N. Meyer of the Bethlehem Steel Co. is now acting as secretary of Subcommittee XV.

The chairmanship of the Special Subcommittee on Bearing Steel changed hands when L. A. Lanning resigned because of retirement and E. S. Rowland, The Timken Roller Bearing Co., accepted the position.

Another special appointment was accomplished when H. L. Fry, Bethlehem Steel Co., was accepted as Committee A-1 representative to Subcommittees 2, 3, 5, and 7 of Committee E-1 on Methods of Testing.

Since the last report several well-known members have died, including H. S. Browall, W. F. Carter, A. R. Ellis, H. S. Krauter, J. H. Nead, H. E. Rowell, E. J. Tompkins, and H. Weisberg.

H. Weisberg, Mechanical Engineer, Public Service Electric and Gas Co., was one of the first engineers to advocate and use welded piping and valves in power plant service, and also pioneered in the use of higher steam pressures and temperatures in steam power-plant design. Mr. Weisberg was a long-time member of Committee A-1 and Subcommittee XXII.

A. R. Ellis, Chairman of the Board, Pittsburgh Testing Laboratory, has been an outstanding figure through the years in the laboratory testing field. Mr. Ellis has been affiliated with ASTM since 1915, and with Committee A-1 and Subcommittees V and IX for many of these past 40 years.

H. S. Browall, Metallurgist, Inland Steel Co., was also a well known and distinguished figure in Committee A-1 for many years, serving on Subcommittees IV, V, VI, and XV. The committee will most certainly miss the counsel of Mr. Browall.

H. S. Krauter, Chief Engineer, American Chain and Cable Co., has been a representative of his company on Committee A-1 and Subcommittees VIII and XXII since 1946.

Another former member of Committee A-1 was J. H. Nead, Metallurgical Consultant to the President, Inland Steel Co. Mr. Nead became affiliated with ASTM in 1911 and for many years was active in Committee A-1 and the former Committee A-4 on Heat Treatment of Iron and Steel.

W. F. Carter represented the Acme Steel Co. on Committee A-1 and Subcommittee XIX. Since 1943 E. J. Tompkins, Metallurgical Engineer, Central Steel & Wire Co., has been a member of Committee A-1 and Subcommittee XV. Mr. Rowell was a relatively recent member of the committee. Being affiliated with the Columbia Steel and Shafting Co., he also was a member of Subcommittee XV.

RECOMMENDATIONS ACCEPTED BY THE ADMINISTRATIVE COMMITTEE ON STANDARDS

On May 18, 1954, the Administrative Committee accepted the recommendation of Committee A-1 to withdraw the Emergency Alternate Provisions relating to phosphorus content in the Tentative Specifications for Seamless Ferritic Alloy Steel Pipe for High-Temperature Service (**A 335 – 53 T**).

On September 28, 1954, the Tentative Specifications for Metal-Arc Welded Steel Pipe for High-Pressure Transmission Service (**A 381 – 54 T**) was accepted by the Administrative Committee on Standards, and they appear in the 1954 Supplement to Book of ASTM Standards, Part 1.

The following recommendations submitted by Committee A-1 were accepted by the Administrative Committee on Standards on October 4, 1954:

Revision of Tentative Specifications for:

Billet-Steel Bars for Concrete Reinforcement (A 15 – 54 T),

General Requirements for Delivery of Rolled

Steel Plates of Flange and Firebox Qualities (A 20 - 54 T),
Boiler and Firebox Steel for Locomotives (A 30 - 54 T),
Open-Hearth Iron Plates of Flange Quality (A 129 - 54 T),
Carbon-Silicon Steel Plates of Intermediate Tensile Ranges for Fusion-Welded Boilers and Other Pressure Vessels (A 201 - 54 T),
Chromium-Manganese-Silicon (CMS) Alloy-Steel Plates for Boilers and Other Pressure Vessels (A 202 - 54 T),
Nickel-Steel Plates for Boilers and Other Pressure Vessels (A 203 - 54 T),
Molybdenum-Steel Plates for Boilers and Other Pressure Vessels (A 204 - 54 T),
High Tensile Strength Carbon-Silicon Steel Plates for Boilers and Other Pressure Vessels (A 212- 54 T),
Manganese-Vanadium Steel Plates for Boilers and Other Pressure Vessels (A 225 - 54 T),
Low and Intermediate Tensile Strength Carbon-Plates of Flange and Firebox Qualities (Plates 2 in. and Under in Thickness) (A 285 - 54 T),
High Tensile Strength Carbon-Manganese-Silicon Steel Plates for Boilers and Other Pressure Vessels (A 299 - 54 T),
Steel Plates for Pressure Vessels for Service at Low Temperatures (A 300 - 54 T),
Chromium-Molybdenum Steel Plates for Boilers and Other Pressure Vessels (A 301 - 54 T)
Manganese-Molybdenum Steel Plates for Boilers and Other Pressure Vessels (A 302 - 54 T),
Low-Carbon High-Nickel Steel Plate for Pressure Vessels (A 353 - 54 T), and
Five Per Cent Chromium, 0.5 Per Cent Molybdenum Steel Plates for Boilers and Other Pressure Vessels (A 357 - 54 T).

Withdrawal of Emergency Alternates Relating to Phosphorus in Specifications for:

Seamless Cold-Drawn Intermediate Alloy-Steel Heat-Exchanger and Condenser Tubes (A 199 - 54 T),
Seamless Intermediate Alloy-Steel Still Tubes for Refinery Service (A 200 - 54 T),
Seamless Alloy Steel Boiler, Superheater, and Heat Exchanger-Tubes (A 213 - 54 T),
Welded Austenitic Stainless Steel Boiler, Superheater, Heat-Exchanger and Condenser Tubes (A 249 - 54 T),
Seamless and Welded Ferritic Stainless Steel Tubing for General Service (A 268 - 54),
Seamless and Welded Austenitic Stainless Steel Tubing for General Service (A 269 - 54),
Seamless and Welded Austenitic Stainless Steel Sanitary Tubing (A 270 - 54),
Seamless Austenitic Chromium-Nickel Steel Still Tubes for Refinery Service (A 271 - 54), and
Seamless and Welded Austenitic Stainless Steel Pipe (A 312 - 54 T).

The revised specifications appear in the 1954 Supplement to Book of ASTM Standards, Part 1, bearing the designations indicated above.

On March 23, 1955, the Administrative Committee on Standards accepted the following recommendations of Committee A-1:

Tentative Specification for:

Untreated Carbon Steel Axles for Export and for General Industrial Use (A 383 - 55 T).

Revision of Tentative Specifications for:

Carbon-Steel Axles for Cars and Tenders (A 21 - 55 T),
Welded and Seamless Steel Pipe (A 53 - 55 T),
Seamless Steel Boiler Tubes (A 83 - 55 T)
Seamless Carbon-Steel Pipe for High-Temperature Service (A 106 - 55 T),
Electric-Resistance-Welded Steel Pipe (A 135 - 55 T),
Seamless Low-Carbon and Carbon-Molybdenum Steel Still Tubes for Refinery Service (A 161 - 55 T),
Electric-Resistance-Welded Steel and Open-Hearth Iron Boiler Tubes (A 178 - 55 T),
Seamless Cold-Drawn Low-Carbon Steel Heat-Exchanger and Condenser Tubes (A 179 - 55 T),
Forged or Rolled Alloy-Steel Pipe Flanges, Forged Fittings, and Valves and Parts for High-Temperature Service (A 182 - 55 T),
Seamless Steel Boiler Tubes for High-Pressure Service (A 192 - 55 T),
Alloy-Steel Bolting Materials for High-Temperature Service (A 193 - 55 T),
Seamless Cold-Drawn Intermediate Alloy-Steel Heat-Exchanger and Condenser Tubes (A 199 - 55 T),
Seamless Intermediate Alloy-Steel Still Tubes for Refinery Service (A 200 - 55 T),
Seamless Carbon-Molybdenum Alloy-Steel Boiler and Superheater Tubes (A 209 - 55 T),
Medium-Carbon Seamless Steel Boiler and Superheater Tubes (A 210 - 55 T),
Seamless Alloy Steel Boiler, Superheater, and Heat-Exchanger Tubes (A 213 - 55 T),
Electric-Resistance-Welded Steel Heat-Exchanger and Condenser Tubes (A 214 - 55 T),
Electric-Resistance-Welded Steel Boiler and Superheater Tubes for High-Pressure Service (A 226 - 55 T),
Welded Austenitic Stainless Steel Boiler, Superheater, Heat-Exchanger and Condenser Tubes (A 249 - 55 T), and

Electric-Resistance-Welded Carbon-Molybdenum Alloy-Steel Boiler and Superheater Tubes (A 250 – 55 T).

Revision of Tentative Specifications for:

Welded and Seamless Open-Hearth Iron Pipe (A 253 – 55 T),
Copper Brazed Steel Tubing (A 254 – 55 T),
Carbon and Alloy-Steel Forgings for Turbine Rotors and Shafts (A 293 – 55 T),
Alloy-Steel Bars to End-Quench Hardenability Requirements (A 304 – 55 T),
Steel Machine Bolts and Nuts and Tap Bolts (A 307 – 55 T),
Seamless and Welded Austenitic Stainless Steel Pipe (A 312 – 55 T),
Alloy-Steel Bolting Materials for Low-Temperature Service (A 320 – 55 T),
Quenched-and-Tempered Steel Bolts and Studs with Suitable Nuts and Plain Washers (A 325 – 55 T),
Seamless and Welded Steel Tubes for Low-Temperature Service (A 334 – 55 T),
Seamless Ferritic Alloy-Steel Pipe for High-Temperature Service (A 335 – 55 T), and
Quenched and Tempered Alloy Steel Bolts and Studs with Suitable Nuts (A 354 – 55 T).

Revision of Standard and Reversion to Tentative:

Spec. for Carbon and Alloy Steel Nuts for Bolts for High-Pressure and High-Temperature Service (A 194 – 55 T).

RECOMMENDATIONS AFFECTING STANDARDS

Committee A-1 is presenting for publication 4 new tentatives and is recommending the revision of 33 tentatives and 18 standards, and the adoption as standard of 11 tentatives. In addition, two standards are recommended to be reverted to tentative with revision, and five standards are being reaffirmed. There are editorial revisions in one standard.

The standards and tentatives affected, together with the revisions recommended, are given in detail in the Appendix.[2]

The recommendations in the report have been submitted to letter ballot of the committee, the results of which will be reported at the Annual Meeting.[3]

ACTIVITIES OF SUBCOMMITTEES

Several of the more important activities being developed in the subcommittees are as follows:

Subcommittee VI on Steel Forgings and Billets has two very important subjects under discussion and development in special task groups. These subjects are the effect of hydrogen in steel forgings, and tests and criteria for judging the sensitivity of heavy rotor forgings to fracture. Both task groups have had several extremely interesting meetings.

Specifications for welded light wall stainless steel pipe in sizes up to 30 in. in outside diameter are being developed in a joint group on Corrosion Resisting Tubular Products of Committee A-1 and Committee A-10. Requirements are being formulated in Subcommittee XXII for seamless pipe of alloy steels which need special heat treatment to develop the desirable optimum of high-temperature properties. Proposed specifications for forged and bored seamless austenitic steel pipe have been tabled, pending developments in the field and a study being made by Committee SP5 of the ASME Steam Power Panel of the current difficulties encountered with austenitic steel pipe in high-temperature service.

The problem of residual alloys in plate steel is being studied by a special task group in Subcommittee XI. While copper was considered the main problem originally, it is now planned to study the effects of copper, nickel, aluminum, and tin.

Subcommittee XV has approved a general requirement specification for bar steels, referred to in last year's report. However, this will not be recommended to Committee A-1 until the individual product specifications can be suitably editorially revised to refer to the general requirements.

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[2] See p. 94.

[3] The letter ballot vote on these recommendations was favorable; the results of the vote are on record at ASTM Headquarters.

In the field of bolting, there has been a large amount of experimental testing by a special task group in Subcommittee XXII. As a result of these tests, it has been concluded that replacement of the present drift test by a torque test would not be practical because of the extremely high torque required for the larger nuts. A modified stripping test employing a conical washer has now been developed and shows considerable promise. However, a large amount of data must be accumulated before rational requirements could be developed for this new test.

After several years of developmental work, standardization of requirements for austenitic steel welding fittings is in its final stages and publication may be expected soon.

This report has been submitted to letter ballot of the committee, which consists of 302 members; 184 members returned their ballots, of whom 183 have voted affirmatively and 1 negatively.

Respectfully submitted on behalf of the committee,

H. B. OATLEY,
Chairman.

H. L. FRY,
Secretary.

EDITORIAL NOTE

Subsequent to the Annual Meeting, Committee A-1 presented to the Society through the Administrative Committee on Standards the following recommendations:

Tentative Specifications for:

Galvanized Steel Transmission Tower Bolts (A 394 – 55 T),

Revision of Tentative Specifications for:

Forged or Rolled Alloy-Steel Pipe Flanges, Forged Fittings, and Valves and Parts for High-Temperature Service (A 182 – 55 T),

Revision of Emergency Alternate Provision for:

Heat-Treated Steel Tires (EA – A 329), and

Withdrawal of Emergency Alternate Provision for:

Steel Tires (EA – A 26).

The revision of Tentative Specifications A 182 was accepted by the Standards Committee on August 31, 1955, and the remaining recommendations were accepted on September 15, 1955; the new and revised specifications together with the revised emergency alternate provision appear in the 1955 Book of ASTM Standards, Part 1.

APPENDIX

RECOMMENDATIONS AFFECTING STANDARDS ON STEEL

In this Appendix recommendations are given affecting certain specifications, both standard and tentative, covering various steel products. The specifications appear in their present form in either the 1952 Book of ASTM Standards, Part 1, or in the 1953 or 1954 Supplements, Part 1, as indicated by the footnote reference.

NEW TENTATIVES

The committee recommends that the following four new tentatives, as appended hereto,[1] be accepted for publication as tentative:

Proposed Tentative Recommended Practices for Ultrasonic Testing and Inspection of Heavy Steel Forgings,
Proposed Tentative Specification for Chromium-Molybdenum Steel Plates for Boilers and Other Pressure Vessels,
Proposed Tentative Specification for Alloy Steel Castings Normalized and Drawn for High Pressure and Elevated Temperature Service, and
Proposed Tentative Specification for Alloy Steel Chain.

REVISIONS OF TENTATIVES

The committee recommends revisions in the following 33 tentatives:

Tentative Specification for Steel for Bridges and Buildings (A 7 – 53 T):[2]

Section 4.—Change the title to read "Bearing Plates" and revise to read as follows:

4. (*a*) Unless otherwise specified, plates used as bearing plates for bridges shall be subjected to mechanical tests and shall conform to the tensile requirements of Section 7.

(*b*) Unless otherwise specified, mechanical tests shall not be required for plates over $1\frac{1}{2}$ in. in thickness used as bearing plates in buildings and for general structural purposes, subject to the requirement that they shall be open hearth or electric furnace steel containing 0.20 to 0.33 per cent carbon by ladle analysis, that the chemical composition shall conform to the requirements of Section 6, and that a sufficient discard shall be made from each ingot to secure sound plates.

Table III.—In footnote *a* change the word "may" to read "shall."

Tentative Specifications for Welded and Seamless Steel Pipe (A 53 – 54 T):[3]

Table I.—Delete the word "Composition" from the title.

Section 3.—Revise to read "The steel or iron shall conform to the chemical requirements prescribed in Table I."

Section 4.—Change the words "prescribed in Table I" to read "specified in Section 3." Add a Paragraph (*b*) to read: "If the analysis of either pipe does not conform to the requirements specified in Section 3, analyses shall be made on additional pipes of double the original number from the same lot, each of which shall conform to the requirements specified."

Tentative Specifications for Seamless Steel Boiler Tubes (A 83 – 54 T):[3]

Section 1.—In Paragraph (*c*) and

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[1] The new tentatives appear in the 1955 Book of ASTM Standards, Part 1.

[2] 1953 Supplement to Book of ASTM Standards, Part 1.

[3] 1954 Supplement to Book of ASTM Standards, Part 1.

throughout the specifications, change the word "type" to read "grade."

Table I.—Delete the word "Composition" from the title.

Section 3.—Revise as indicated above for Section 3 in Specifications A 53.

Section 4.—In Section 4(*b*) delete "(*b*)" from the reference to Section 3(*b*).

Tentative Specifications for Seamless Carbon-Steel Pipe for High-Temperature Service (A 106 - 52 T):[4]

Section 2(a).—Delete the words "for Grade A and Grade B pipe." Change the words "one or more" to read "either or both."

Section 3.—Revise to read "The steel shall conform to the chemical requirements prescribed in Table I."

New Section.—Add a new Section 4 titled "Ladle Analysis" to read as follows, renumbering subsequent sections accordingly.

> 4. An analysis of each heat of steel shall be made by the steel manufacturer to determine the percentages of the elements specified in Section 3. The chemical composition thus determined, or that determined from a check analysis made by the manufacturer, if the latter has not manufactured the steel, shall be reported to the purchaser or his representative, and shall conform to the requirements specified in Section 3.

Section 4.—Number the present text as Section 5(*a*) and change the words "purchaser's inspector" to read "purchaser." Change the words "prescribed in Table I" to read "specified in Section 3." Reference the present footnote 4 on lot size after the word "lot" in two places. Add a Paragraph (*b*) to read as follows:

> (*b*) If the analysis of one of the tests specified in Paragraph (*a*) does not conform to the requirements specified in Section 3, analyses shall be made on additional pipes of double the original number from the same lot, each of which shall conform to the requirements specified.

Table I.—Add a new grade C with the following chemical requirements:

Carbon, max, per cent	0.35
Manganese, per cent	0.29 to 1.06
Phosphorus, max, per cent	0.048
Sulfur, max, per cent	0.058
Silicon, min, per cent	0.10

Table II.—Add tensile requirements for the new grade C as follows:

Tensile strength, min, psi	70 000
Yield point, min, psi	40 000

All the elongation values shall be the same as those for grade B except the minimum elongation in 2 in. in the longitudinal direction when the round specimen is used shall be 20 per cent

Section 11(a).—Revise to read: "If the results of any mechanical tests of any lot do not conform to the requirements specified in Sections 6 and 7, retests shall be made on additional pipes of double the original number from the same lot, each of which shall conform to the requirements specified."

Tentative Specifications for Electric-Resistance-Welded Steel Pipe (A 135 - 54 T):[3]

Section 2.—Delete the words "unless otherwise specified."

Section 3.—Revise to read: "The steel shall conform to the following chemical requirements."

Section 4.—Delete the sentence: "This analysis shall be made from a test ingot taken during the pouring of the heat."

Section 5(a).—Revise to read as follows:

> (*a*) An analysis may be made by the purchaser on samples of pipe selected at random and shall conform to the requirements specified in Section 3. The number of samples shall be determined as follows:

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[4] 1952 Book of ASTM Standards, Part 1.

Pipe Size, in.	Number of Samples Selected
Under 6...........	2 from each lot of 400 pipes or fraction thereof
60 to 20, incl.......	2 from each lot of 200 pipes or fraction thereof
Over 20 to 30, incl..	2 from each lot of 100 pipes or fraction thereof

Tentative Specifications for Electric-Fusion-Welded Steel Pipe for High Temperature Service (A 155 – 52a T):[4]

Table I.—Change the words "Identification Symbol" to read "Grade."

Section 4.—Revise to read as indicated above for new Section 4 in Specifications A 106.

Section 5.—Letter the present text as Paragraph (*a*), and after the word "lot" reference a new footnote 6 to read: "A lot shall consist of the number of lengths specified in Sections 5, 10, and 11, of the same size and wall thickness from any one heat of steel." Add a Paragraph (*b*) to read as indicated above for Section 4 in Specifications A 106.

Section 11(a).—Revise to read as indicated above for Section 11(*a*) in Specifications A 106, inserting the words "of pipe material" after the words "mechanical tests."

Tentative Specifications for Seamless Low - Carbon and Carbon - Molybdenum Steel Still Tubes for Refinery Service (A 161 – 54 T):[3]

Table I.—Delete the word "Composition" from the title. For Grade T1 change the required molybdenum content from the present "0.45 to 0.66" to read "0.44 to 0.65" per cent.

Section 2.—Delete the words "and shall be."

Section 4.—Revise to read: "The steel shall conform to the chemical requirements prescribed in Table I." Delete the present Paragraph (*b*).

New Section.—Add a new Section 5 titled "Ladle Analysis" to read as follows, renumbering the subsequent sections accordingly.

> 5. An analysis of each heat shall be made by the manufacturer to determine the percentages of the elements specified in Section 4. When requested by the purchaser, the chemical composition thus determined shall be reported to the purchaser or his representative and shall conform to the requirements specified in Section 4.

Section 5.—Renumber as Section 6, and revise to read as follows:

> 6. (*a*) An analysis shall be made of one billet from each heat or of two tubes from each lot of 100 tubes or fraction thereof. Drillings for analysis shall be taken from several points around each tube selected for analysis and when taken from the billet, they may be obtained by drilling parallel to the axis at a point midway between the outside and center of the piece. The chemical composition thus determined shall conform to the requirement specified in Section 4.
>
> (*b*) If the analysis of one of these test specimens does not conform to the requirements specified in Section 4, an analysis of two billets from the same heat or an analysis of two tubes from the same lot may be made, each of which shall conform to the requirements specified in Section 4.

Tentative Specifications for Electric-Resistance-Welded Steel and Open-Hearth Iron Boiler Tubes (A 178 – 54 T):[3]

Section 1(c).—Change the word "type" to "grade" here and throughout the specifications.

Table I.—Delete the word "Composition" from the title.

Section 2.—Revise to read: "The steel or iron shall be made by either or both of the following processes: open-hearth or electric furnace."

Section 4.—Revise to read: "The steel or iron shall conform to the chemical requirements prescribed in Table I."

Section 5.—In Paragraph (*a*) change the words "prescribed in Table I" to read "specified in Section 4."

In the first sentence after the words "the analysis of" add the words "one length of flat rolled stock or." Add a new third sentence to read: "If on flat rolled stock, samples shall be milled from the entire cross-section of the stock."

Change Paragraph (*b*) to read: "If the analysis of one length of flat rolled stock or of either tube does not conform to the requirements specified, an analysis of two additional lengths of flat rolled stock or two additional tubes of the same lot shall be made, each of which shall conform to the requirements specified in Section 4."

Tentative Specifications for Seamless Cold-Drawn Intermediate Alloy-Steel Heat - Exchanger and Condenser Tubes (A 199 - 54 T):[3]

Table I.—Delete the word "Composition" from the title. For grades T3b, T 4, and T 11, change the required molybdenum content from the present "0.45 to 0.66" to read "0.44 to 0.65" per cent.

Section 4.—Delete the present Paragraph (*b*) and revise to read: "The steel shall conform to the chemical requirements prescribed in Table I."

New Section.—Add a new Section 5 titled "Ladle Analysis" to read as indicated above for new Section 5 in Specifications A 161, renumbering subsequent sections accordingly.

Section 5.—Renumber as Section 6, and revise Paragraph (*b*) to read as indicated above for Section 5(*b*) in Specifications A 161. Revise Paragraph (*a*) to read as follows:

> (*a*) When requested by the purchaser, an analysis shall be made of one billet per heat or of two tubes from each heat or from each lot of 250 tubes or fraction thereof. Drillings for analysis shall be taken from several points around each tube selected for analysis. Drilling for billets shall be taken at a point midway between the outside and center of the billet by drilling parallel to the axis. The chemical composition thus determined shall conform to the requirements specified in Section 4.

Tentative Specifications for Seamless Intermediate Alloy-Steel Still Tubes for Refinery Service (A 200 - 54 T):[3]

Table I.—Delete the word "Composition" from the title. For grades T 3b, T 4, and T 11 change the required molybdenum content from the present "0.45 to 0.66" to read "0.44 to 0.65" per cent.

Section 4.—Revise as indicated above for Section 4 in Specifications A 199.

New Section.—Add a new Section 5 titled "Ladle Analysis" to read as follows, renumbering subsequent sections accordingly.

> 5. Analysis of each heat of steel shall be made to determine the percentages of the elements specified in Section 4. The chemical composition thus determined shall be reported to the purchaser or his representative, and shall conform to the requirements specified in Section 4.

Section 5.—Renumber as Section 6. In Paragraphs (*a*) and (*b*) change the words "prescribed in Table I" to read "specified in Section 4."

Tentative Specifications for Seamless Carbon - Molybdenum Alloy - Steel Boiler and Superheater Tubes (A 209 - 54 T):[3]

Table I.—Delete the word "Composition" from the title. For grades T1, T1a, and T1b change the required molybdenum content from the present "0.45 to 0.66" to read "0.44 to 0.65" per cent.

Section 2.—Delete the words "and shall be."

Section 4.—Revise as indicated above for Section 4 in Specifications A 199.

New Section.—Add a new Section 5 titled "Ladle Analysis" to read as follows, renumbering subsequent sections accordingly.

> 5. An analysis of each heat of steel shall be made to determine the percentages of the elements specified in Section 4. The chemical

composition thus determined or a report of check analysis as specified in Section 6(*a*) shall be reported to the purchaser or his representative and shall conform to the requirements specified in Section 4.

Section 5.—Renumber as Section 6, and revise Paragraph (*b*) to read as indicated above for Section 5(*b*) in Specifications A 161. Revise Paragraph (*a*) to read as follows, retaining the present table at the end.

(*a*) At the request of the purchaser, an analysis shall be made by the manufacturer of one billet for each heat or the number of tubes selected at random as specified in the following table and this shall conform to the requirements specified in Section 4. Drillings for analysis shall be taken from several points around each tube selected for analysis. Drillings from billets shall be taken at a point midway between the outside and center of the billet by drilling parallel to the axis.

Tentative Specifications for Medium-Carbon Seamless Steel Boiler and Superheater Tubes (A 210 - 54 T):[3]

Section 2.—Delete the words "and shall be."

Section 4.—Revise to read as follows retaining the present table but deleting Paragraph (*b*): "The steel shall conform to the following chemical requirements:"

Revise the maximum permissible carbon content from the present "0.35" to read "0.27" per cent.

New Section.—Add a new Section 5 to read as indicated above for new Section 5 in Specifications A 209, renumbering subsequent sections accordingly.

Section 5.—Renumber as Section 6, and revise Paragraph (*b*) to read as indicated above for Section 5(*b*) in Specification 161. Revise Paragraph (*a*) to read as follows, retaining the present table at the end.

(*a*) At the request of the purchaser, an analysis of one billet or an analysis as specified in the following table shall be made and shall conform to the requirements specified in Section 4. Drillings for analysis shall be taken from several points around each tube selected for analysis. Drillings for billets shall be taken at a point midway between the outside and center of the billet by drilling parallel to the axis.

Section 19(*a*).—Change the word "type" to read "grade."

Tentative Specifications for Seamless Alloy Steel Boiler, Superheater, and Heat Exchanger Tubes (A 213 - 54 T):[3]

Table I.—Delete the word "Composition" from the title. Change the words "Identification Symbol" to read "Grade." Delete the entire second line now identified as "Grade." For grades T3b, T11, and T12, change the required molybdenum content from the present "0.45 to 0.66" to read "0.44 to 0.65" per cent.

Table II.—Change the general format as indicated above for Table I.

Section 2.—Add the words "except that grades T12 and T17 may be made by the open hearth process."

Section 3.—Delete Paragraph (*b*).

New Section.—Add a new Section 4 titled "Heat Treatment" to read as follows, renumbering subsequent sections accordingly.

4. (*a*) All material shall be furnished in the heat-treated condition unless otherwise agreed upon by the manufacturer and the purchaser and so specified in the order. The heat treatment shall be performed by a method and at a temperature selected by the manufacturer.

(*b*) If any controlled structural characteristics are required these shall be so specified as to be a guide as to the most suitable heat treatment.

Section 4.—Renumber as Section 5 and revise to read as follows, deleting the present Paragraph (*b*): "The steel shall conform to the chemical requirements prescribed in Tables I and II."

New Section.—Add a new Section 6 to read as indicated above for new Section 5 in Specifications A 209, renumbering subsequent sections accordingly.

Section 5.—Renumber as Section 7 and in Paragraphs (*a*) and (*b*) change the words "prescribed in Tables I and II" to read "specified in Section 5."

Section 19(a).—Renumber as Section 21 and change the words "identification symbol" to read "grade."

Tentative Specifications for Electric-Resistance-Welded Steel Heat-Exchanger and Condenser Tubes (A 214 - 54 T):[3]

Section 1.—In Note 1, second sentence, change the word "prescribed" to read "specified."

Section 4.—Revise to read: "The steel shall conform to the following chemical requirements:"

Section 5.—Revise as indicated above for Section 5 in Specifications A 178.

Tentative Specifications for Electric-Resistance-Welded Steel Boiler and Superheater Tubes for High-Pressure Service (A 226 - 54 T):[3]

Section 2.—Delete the words "and shall be."

Section 4.—Revise to read: "The steel shall conform to the following chemical requirements:"

Section 5.—Revise as indicated above for Section 5 in Specifications A 178.

Tentative Specifications for Welded Austenitic Stainless Steel Boiler, Superheater, Heat Exchanger and Condenser Tubes (A 249 - 54 T):[3]

Table I.—Delete the word "Composition" from the title. Change the words "Identification Symbol" to read "Grade." Delete the entire second line now identified as grade.

Section 3.—Delete the present Paragraph (*b*) and add new Paragraphs (*b*) and (*c*) to read as follows:

> (*b*) At the manufacturer's option, tubing may be furnished either hot finished or cold finished.
>
> (*c*) The tubes shall be pickled free from scale. When bright annealing is used, pickling is not necessary.

New Section.—Add a new Section 4 as indicated above for new Section 4 in Specifications A 213, renumbering subsequent sections accordingly.

Section 4.—Renumber as Section 5 and revise to read as follows, deleting the present Paragraph (*b*): "The steel shall conform to the chemical requirements prescribed in Table I."

New Section.—Add a new Section 6 to read as indicated above for new Section 5 in Specifications A 209, renumbering subsequent sections accordingly.

Section 5.—Renumber as Section 7 and revise to read as follows:

> (*a*) An analysis of either one length of flat rolled stock or one tube shall be made on each heat of steel. Drillings for analysis shall be taken from several points around each tube selected for analysis and, if on flat rolled stock, samples shall be milled from the entire cross-section of the stock. The chemical composition thus determined shall conform to the requirements specified in Section 5.
>
> (*b*) If the analysis of one of these test specimens does not conform to the requirements specified in Section 5, an analysis of each length of flat rolled stock or tube from the same heat may be made, and all lengths of flat rolled stock or tubes thus conforming to the requirements shall be accepted.

Section 20.—Renumber as Section 22 and delete Paragraph (*b*).

Tentative Specifications for Electric-Resistance-Welded Carbon-Molybdenum Alloy-Steel Boiler and Superheater Tubes (A 250 - 54 T):[3]

Table I.—Delete the word "Composition" from the title. For all three grades, change the required molybdenum content from the present "0.45 to 0.66" to read "0.44 to 0.65" per cent.

Section 2.—Delete the words "and shall be."

Section 4.—Revise to read as follows, deleting the present Paragraph (*b*): "The steel shall conform to the chemical requirements prescribed in Table I."

New Section.—Add a new Section 5 to

read as indicated above for new Section 5 in Specifications A 209, renumbering subsequent sections accordingly.

Section 5.—Renumber as Section 6. Letter the present text as Paragraph (*a*), changing the word "strip" to "flat rolled stock" in the fourth and seventh lines, and changing the last word "strip" to read "stock." Add a Paragraph (*b*) to read as follows:

> (*b*) If the analysis of one of these test specimens does not conform to the requirements specified in Section 4, an analysis of two additional lengths of flat rolled stock or two additional tubes from the same heat may be made. Each of the lengths of flat rolled stock or tubes tested shall conform to the requirements specified in Section 4.

Table II.—Delete the words "Identification Symbol" in the first column heading.

Section 21(a).—Change the words "identification symbol" to read "grade."

Tentative Specifications for Welded and Seamless Open-Hearth Iron Pipe (A 253 - 54 T):[3]

Table I.—Delete the word "Composition" from the title. Change the word "Type" to read "Grade."

Section 3.—Revise to read: "The iron shall conform to the chemical requirements prescribed in Table I."

Section 4.—Letter the present text as Paragraph (*a*), changing the words "Table I" to read "Section 3" in the third sentence. Add a new Paragraph (*b*) to read: "If the check analysis specified in Paragraph (*a*) does not conform to the requirements specified in Section 3, analysis shall be made on additional pipes of double the original number from the same lot, each of which shall conform to the requirements specified."

Table II.—Change the word "Type" to read "Grade."

Tentative Specifications for Copper Brazed Steel Tubing (A 254 - 54 T):[3]

Section 4.—Revise to read: "The steel shall conform to the following chemical requirements:"

Section 5.—Letter the present text as Paragraph (*a*), revising the first sentence to read: "An analysis of two tubes from each lot of 200 tubes or fraction thereof may be made by the purchaser."

Add a new Paragraph (*b*) to read as indicated above for Section 4(*b*) in Specifications A 253, referring to "Section 4" instead of "Section 3," and to "tubes" instead of "pipes."

Tentative Specification for Low and Intermediate Tensile Strength Carbon Silicon Steel Plates for Machine Parts and General Construction (A 284 - 52 T):[4]

Section 1.—In Paragraph (*a*) delete the qualifying phrase "(other than pressure vessels)."

Table I.—Revise to read as shown in the accompanying Table I.

Tentative Specification for Carbon and Alloy Steel Forgings for Turbine Rotors and Shafts (A 293 - 52 T):[4]

Section 11.—In Paragraph (*a*) change the reference to Methods E 8 to refer to Methods A 370 for Mechanical Testing of Steel Products.[3]

Revise Paragraphs (*b*) and (*c*) to read as follows:

> (*b*) The yield strength prescribed in Table III for classes 1 and 7 shall be determined by the offset method, using an offset value of 0.2 per cent of the gage length, or by the total extension under load method, using an extension of 0.005 in. per inch (0.5 per cent) for class 1 and 0.006 in. per inch (0.6 per cent) for class 7. The yield strength preseribed for classes 2 to 6, incl., shall be determined by the offset method, using an offset value of 0.02 per cent. The yield strength for class 8 shall be determined using as offset value of 0.01 per cent.
>
> (*c*) The yield point or yield strength shall be determined at a rate of separation of the crossheads under load not to exceed $\frac{1}{16}$ in. per min per inch of gage length. The tensile strength shall be determined at a rate of separation of the crossheads under load not to exceed $\frac{1}{2}$ in. per min per inch of gage length.

TABLE I.—CHEMICAL REQUIREMENTS.
(Revision of Table I, Specification A 284.)

	Grade A		Grade B		Grade C		Grade D	
	Ladle Analysis	Check Analysis	Ladle Analysis	Check Analysis	Ladle Analysis	Check Analysis	Ladle Analysis	Check Analysis
Carbon, max, per cent, for thickness as follows:								
1 in. and under....	0.19	0.23	0.21	0.25	0.24	0.28	0.27	0.31
Over 1 to 2 in. incl..........	0.21	0.25	0.24	0.28	0.27	0.31	0.29	0.33
Over 2 to 4 in. incl..........	0.23	0.27	0.27	0.31	0.29	0.33	0.31	0.35
Over 4 to 8 in. incl..........	0.25	0.29	0.31	0.35	0.33	0.37	0.35	0.39
Over 8 to 12 in. incl..........	0.27	0.31	0.34	0.38	0.36	0.40	....	....
Manganese, max, per cent..........	0.90	0.94	0.90	0.94	0.90	0.94	0.90	0.94
Phosphorus, max, per cent........	0.04	0.05	0.04	0.05	0.04	0.05	0.04	0.05
Sulfur, max, per cent.	0.05	0.063	0.05	0.063	0.05	0.063	0.05	0.063
Silicon, per cent	0.10 to 0.30	0.08 to 0.33	0.15 to 0.30	0.13 to 0.33	0.15 to 0.30	0.13 to 0.33	0.15 to 0.30	0.13 to 0.33

Table I.—Delete the requirements for the present class 7 and add two new classes 7 and 8 as follows:

	Class 7	Class 8
Carbon, max, per cent..........	0.40	0.40
Manganese, max, per cent.......	1.00	1.00
Phosphorus, max, per cent.......	0.050	0.050
Sulfur, max, per cent..........	0.050	0.050
Silicon, per cent..	0.15 to 0.35	0.15 to 0.35
Nickel, per cent..	2.50 min	0.50 max
Chromium, per cent..........	0.80 min	0.85 to 1.25
Molybdenum, per cent..........	0.45 min	1.00 to 1.50
Vanadium, per cent..........	0.15 min	0.20 to 0.30

Section 14(b).—Change the words "and any part of the fracture is more than ¾ in. from the center of the gage length" to read "and any part of the fracture is outside of the middle half of the gage length."

Figure 1.—Replace with a drawing similar to Fig. 6 of Methods A 370.[3]

Table II.—Revise Footnote *c* to read "For classes 7 and 8."

Table III.—Delete the requirements for the present class 7 and add requirements for new classes 7 and 8 as follows:

	Class 7	Class 8
Tensile strength, min, psi..	120 000	120 000
Yield strength, min, psi..	100 000	90 000
Elongation in 2 in., min, per cent:		
Longitudinal prolongation..............	15	12
Radial body...........	12	10
Tangential body:		
Greater than ½ radius at ends...........	12	10
½ or less radius at ends..............	10	8
Reduction of area, min, per cent:		
Longitudinal prolongation...............	35	25
Radial body...........	25	20
Tangential body:		
Greater than ½ radius at ends............	25	20
½ or less radius at ends.............	20	16

Change Footnote *a* to read: "At 0.2 per cent offset for classes 1 and 7, 0.02 per cent offset for classes 2 to 6, incl., and 0.01 per cent offset for class 8."

Tentative Specification for Carbon-Steel Bars Subject to Mechanical Property Requirements (A 306 – 52a T):[4]

Section 2.—Revise to read as follows:

2. (*a*) The purchaser shall specify the desired grade of steel by its grade designation or by the corresponding limits of tensile strength as described in Table I.

(*b*) If the use of bessemer steel is permissible for grades 55, 60, 65, and 70 as specified in Section 3, orders should so state.

(*c*) Bars which are bent cold in fabrication should be clearly designated so that the bend requirements of Table II may be applied.

Tentative Specifications for Seamless and Welded Austenitic Stainless Steel Pipe (A 312 – 54 T):[3]

Table I.—Delete the word "Composition" from the title. Change the words "Identification Symbol" to read "Grade" here and throughout the specification. Delete the line identified presently as Grade.

Section 3.—Revise Paragraphs (*b*) and (*c*) to read as follows:

(*b*) At the manufacturer's option, pipe may be furnished either hot finished or cold finished.

(*c*) The pipe shall be pickled free from scale. When bright annealing is used, pickling is not necessary.

Section 5.—Revise to read as follows:

5. (*a*) All material shall be furnished in the heat treated condition unless otherwise agreed between the manufacturer and the purchaser and so specified in the order. This heat treatment shall be performed by a method and at a temperature selected by the manufacturer.

(*b*) If any controlled structural characteristics are required these shall be so specified as to be a guide as to the most suitable heat treatment.

Section 6.—Revise to read: "The steel shall conform to the chemical requirements prescribed in Table I or to other chemical requirements as specified in the order."

Section 18.—Revise to read as follows:

18. Pipe lengths shall be in accordance with the following regular practice:

(*a*) Unless otherwise agree upon, all sizes from $\frac{1}{8}$ in. to and including 8 in. nominal outside diameter (Note) are available in a length up to 25 ft. The aim range will be 20 to 25 ft with the permissible range of 15 to 25 ft. Short lengths are acceptable and the number and minimum length shall be agreed upon between the manufacturer and the purchaser.

NOTE.—Sizes 10 and 12 in., listed in Table III are not generally available, and are furnished only by special agreement.

(*b*) If definite cut lengths are desired, the lengths required shall be specified in the order. No pipe shall be under the specified length and not more than $\frac{1}{4}$ in. over that specified.

(*c*) No jointers are permitted unless otherwise specified.

Supplementary Requirements.—Revise the supplementary requirements to read as follows, retaining the present footnote 5 in Supplementary Requirement S 5.

S1. These supplementary requirements shall be considered only when specified in the order, in which event they shall be performed at the mill at the purchaser's expense.

Unless otherwise specified in the order, the tests covered in Supplementary Requirements S2 to S5 shall be performed. This number of supplementary tests is commonly considered sufficient to determine the quality of pipe intended for severe service. However, more or fewer tests may be agreed upon at the purchaser's discretion.

S2. *Check Analysis.*—For all pipe 5 in. and larger in nominal size there shall be one check analysis made of a representative sample from one piece for each ten lengths or fraction thereof from each heat of steel.

For pipe smaller than 5 in. in nominal size there shall be one check analysis made from ten lengths per heat of steel or from 10 per cent of the number of lengths per heat of steel, whichever number is smaller.

Individual lengths failing to conform to the chemical requirements specified in Section 6 shall be rejected.

S3. *Transverse Tension Tests.*—There shall be one transverse tension test made from one end of 10 per cent of the lengths furnished per heat of steel. This applies only to pipe 8 in. and larger in nominal size.

If a specimen from any length fails to conform to the mechanical properties specified in Section 9, that length shall be rejected.

S4. *Flattening Tests.*—The flattening test specified in Section 11 shall be made on specimens from one end of each length of pipe. This requirement applies only to pipe over 2 in. in nominal diameter. Crop ends may be used. If the specimen from any length fails to conform to the specified requirement, that length shall be rejected.

S5. *Etching Tests.*—An etching test shall be made on a transverse section from one end of each length and shall show sound, homogenous, and reasonably uniform material, free from injurious laminations, cracks, and similar objectionable defects. If the specimen of any length shows objectionable defects, one retest shall be permitted from same end. If this fails the length shall be rejected. The rings for the flattening tests (Supplementary Requirement S4) either before or after flattening, may be used for etch tests.

Tensile strength, min, psi	125 000
Yield point, min, psi	105 000
Elongation in 2 in., min, per cent	16
Reduction of area, min, per cent	50

Section 9(a).—Revise the first sentence to read: "Material of grades L7, L9, L10, L43, and B8F shall show a minimum impact strength of 15 ft-lb at the test temperature."

TABLE II.—CHEMICAL REQUIREMENTS.
(Addition to Table I, Specifications A 320.)

Identification Symbol	L43	
Grade	Nickel-Chromium-Molybdenum (AISI 4340)	
	Range	Check Variation, Over or Under[a]
Carbon, per cent	0.38 to 0.43	0.02
Manganese, per cent	0.60 to 0.85	0.03
Phosphorus, max, per cent	0.040	0.005 over
Sulfur, max, per cent	0.040	0.005 over
Silicon, per cent	0.20 to 0.35	0.02
Nickel, per cent	1.65 to 2.00	0.05
Chromium, per cent	0.70 to 0.90	0.03
Molybdenum, per cent	0.20 to 0.30	0.02

Tentative Specifications for Alloy-Steel Bolting Materials for Low-Temperature Service (A 320 – 53 T):[2]

Section 1.—In the first sentence of Paragraph (*b*) and also in the Note, change the wording to indicate that eight grades of material are now covered.

Section 4.—Revise the second sentence to read: "Grades L7, L9, and L43, shall be reheated to above the upper critical temperature and quenched and tempered."

Table I.—Add requirements for new grade L43 as shown in the accompanying Table II, retaining the present footnotes *a* and *b*.

Table II.—Grade L43 in diameters up to 4 in., incl., shall have the following tensile requirements:

Section 14(a).—In addition to grades L7 and L10, new grades L43 and L86 should be referenced as requiring grade 4 nuts of Specifications A 194.[2]

Tentative Specifications for Seamless and Welded Steel Pipe for Low-Temperature Service (A 333 – 54 T):[3]

Table I.—Delete the word "Composition" from the title, and the word "Ferritic" from the first column heading.

Section 6.—Revise to read: "The steel shall conform to the chemical requirements prescribed in Table I."

Section 7.—Revise to read as indicated above for new Section 4 in Specifications A 106, except that the reference to "Section 3" should be changed to read "Section 6."

Section 8.—Revise Paragraph (*a*) to

read as follows, retaining the present table: "At the request of the purchaser, an analysis of one billet or two samples of flat rolled stock from each heat or of two pipes from each lot shall be made by the manufacturer. A lot of pipe shall consist of the following:" Add a footnote referenced after the word "lot" to read: "A lot shall consist of the number of lengths specified in Section 8, of the same size and wall thickness from any one heat of steel."

In Paragraph (*b*) add a new third sentence to read: "Samples taken from flat rolled stock shall be milled from the entire cross-section of the stock." In the last sentence change the words "Table I" to read "Section 6."

In Paragraph (*c*) change the words "Table I" to read "Section 6."

Section 17(d).—Change the word "specified" to read "prescribed."

Tentative Specifications for Seamless and Welded Steel Tubes for Low-Temperature Service (A 334 - 54 T):[3]

Table I.—Delete the word "Composition" from the title. Delete the word "Ferritic" in the column heading.

Section 5.—Revise to read as follows, deleting the present Paragraph (*b*): "The steel shall conform to the chemical requirements prescribed in Table I."

New Section.—Add a new Section 6 to read as indicated above for new Section 5 in Specifications A 200, using "Section 5" in place of the words "Section 4," and renumbering subsequent sections accordingly.

Section 6.—Renumber as Section 7 and revise to read as follows:

(*a*) An analysis of either one billet or one length of flat rolled stock or one tube shall be made for each heat of steel. Drillings for analysis shall be taken from several points around each tube selected for analysis and, if on the flat rolled stock, samples shall be milled from the entire cross-section of the stock. When taken from the billet, drilling shall be obtained by drilling parallel to the axis at a point midway between the outside and center of the piece. The chemical composition thus determined shall conform to the requirements specified in Section 5.

(*b*) If the analysis made in accordance with Paragraph (*a*) does not conform to the requirements specified in Section 5, an analysis of each billet or length of flat rolled stock or tube from the same heat may be made, and all billets, stock, or tubes thus conforming to the requirements shall be accepted so far as chemical composition is concerned.

Section 16.—Renumber as Section 17 and in Paragraph (*c*) change the word "specified" to read "prescribed."

Section 22.—Renumber as Section 23 and change the words "Identification Symbol" to read "Grade."

Tentative Specifications for Seamless Ferritic Alloy Steel Pipe for High-Temperature Service (A 335 - 53 T):[2]

Table I.—In Table I and throughout the specifications, change the words "identification symbol" to read "grade." In Table I delete the line now identified as "Grade." For grades P1, P2, P3b, P7, P11, P12, and P15, change the required molybdenum content from the present "0.45 to 0.66" to read "0.44 to 0.65" per cent.

Section 2(a).—Revise to read: "The steel shall be made by the electric furnace process or other processes approved by the purchaser, except that grades P1, P2, and P12 may be made by the open-hearth process."

Section 5.—Revise to read: "The steel shall conform to the chemical requirements prescribed in Table I."

Section 7(a).—Revise to read as follows, retaining the present table: "At the request of the purchaser, an analysis of two pipes from each lot shall be made by the manufacturer. A lot of pipe shall consist of the following:" Add a footnote referenced after the word "lot" to read: "A lot shall consist of the number of lengths specified in Section 8, of the same size and wall thickness from any on heat of steel."

Tentative Specification for Alloy Steel Seamless Drum Forgings (A 336 - 51 T):[4]

Section 1(b).—Revise the first sentence to read: "Fifteen classes are covered, including nine ferritic steels, and six austenitic steels."

Table I.—Add a new Footnote *c* referenced after the phosphorus and sulfur limits for classes F1, F2, F22, F30, F31, and F32 to read: "When acid open hearth steel is used the maximum permissible phosphorus and sulfur contents shall be 0.050 per cent for classes F1, F2, F30, F31, and F32 and 0.040 per cent for class F22."

Redesignate the present class F5 as F5a and add a new class F5 with the following chemical requirement:

Carbon, max, per cent	0.15
Manganese, per cent	0.30 to 0.60
Phosphorus, max, per cent	0.030
Sulfur, max, per cent	0.030
Silicon, max, per cent	0.50
Nickel, max, per cent	0.50
Chromium, per cent	4.0 to 6.0
Molybdenum, per cent	0.45 to 0.65

Table III.—Change the words "identification symbol" to read "class" and delete the line now identified as grade. Redesignate class F5 as class F5a, revise the requirements for class F22 to read as follows, and add requirements for a new class F5 as follows:

	Class F5	Class F22
Tensile strength, min, psi	60 000	70 000
Yield point, min, psi	36 000	40 000
Elongation in 2 in., min, per cent	22	20
Reduction of area, min, per cent	50	30

Section 11.—In Paragraph (*a*) change the reference to Methods E 8 to refer to Methods A 370 for Mechanical Testing of Steel Products.[3]

Revise Paragraphs (*b*) and (*c*) to read as follows:

> (*b*) The yield strength shall be determined at 0.2 per cent offset by a total extension under load of 0.005 in. per inch of gage length.
>
> (*c*) The yield point or yield strength shall be determined at a rate of separation of the crossheads under load not to exceed $\frac{1}{16}$ in. per minute per inch of gage length. The tensile strength shall be determined at a rate of separation of the crossheads under load not to exceed $\frac{1}{2}$ in. per minute per inch of gage length.

Section 14(b).—Change the words "and any part of the fracture is more than $\frac{3}{4}$ in. from the center of the gage length" to read "and any part of the fracture is outside of the middle half of the gage length."

Fig. 1.—Replace with a drawing similar to Fig. 6 in Methods A 370.[3]

Tentative Specifications for Ferritic Steel Castings for Pressure Containing Parts Suitable for Low-Temperature Service (A 352 - 52 T):[4]

Section 1(b).—Revise the last sentence to read: "The recommended minimum service temperature is the lowest temperature at which the material will meet the impact requirements of these specifications."

Section 10(b).—Revise to read as follows:

> (*b*) Unless otherwise agreed upon the grades of steel covered by these specifications shall be tested at the following temperatures (Note):
>
> | Grade | Testing Temperature, F |
> |---|---|
> | LCB | −50 |
> | LC1 | −75 |
> | LC2 | −100 |
> | LC3 | −150 |
>
> If other test temperatures are agreed upon, they should preferably be selected in increments of 25 F. The standard test temperatures shall be −25 F, −50 F, −75 F, −100 F, etc.
>
> NOTE.—This table signifies that these grades are recommended for use down to the temperature indicated if each heat of steel meets the impact test requirements at these temperatures. It should be noted that in the present state of the science of steel melting not all heats of these materials will meet the impact requirements at the lowest temperature shown in this table. For example, much of the cast carbon steel now pro-

duced within the chemical limits of grade LCB will not meet the impact requirements at temperatures any lower than −25 F. However, the committee formulating these specifications does not wish to restrict advances in the use of such material and, hence, has set lower temperature limits somewhat below those which could be readily met in commercial practice at the time of issuing these specifications. Purchasers of castings should check the lowest practical temperature of use with individual foundries inasmuch as melting practices vary and are continually subject to improvement.

Tentative Specifications for Electric-Fusion-Welded Austenitic Chromium-Nickel Alloy Steel Pipe for High Temperature Service (A 358 - 52 T):[4]

Table I.—In the column heading for the first column, delete the word "designation" after the word "grade." Also add a reference to types 309 and 310 austenitic steels.

Section 3(b).—Add the word "deposited" before the words "weld metal."

Section 4.—Revise to read as indicated above for new section 4 in Specifications A 106, except that the reference to "Section 3" should be changed to read "Section 5."

Section 5.—Reletter the present text as Paragraph (*a*) and add a footnote referenced after the word "lot" to read: "A lot shall consist of the number of lengths specified in Section 5 of the same size and wall thickness from any one heat of steel."

Add a new Paragraph (*b*) to read as described above for Section 4(*b*) in Specifications A 106.

Section 11(a).—Revise to read: "If the results of any mechanical tests of pipe material of any lot do not conform to the requirements specified in Sections 7 and 8, retests shall be made on double the original number from the same lot, each of which shall conform to the requirements specified."

Tentative Specifications for Ferritic Alloy Steel Forged and Bored Pipe for High Temperature Service (A 369 - 53 T):[2]

Table I.—Change the words "identification symbol" to read "grades" here and throughout the specifications. Delete the line presently identified as "grade." Delete all chemical requirements presently identified as "ladle analysis." For grades FP1, FP2, FP3b, FP11, FP12, and FP7 change the required molybdenum content from the present "0.45 to 0.66" to read "0.44 to 0.65" per cent.

Section 2(a).—Revise to read: "The steel shall be made by the electric furnace process or other processes approved by the purchaser, except that grades FP1, FP2, and FP12 may be made by the open-hearth process."

Section 7.—Revise to read: "The steel shall conform to the chemical requirements prescribed in Table I."

Section 15(b).—Change the word "prescribed" to read "specified."

Tentative Specification for Carbon and Alloy Steel Forgings for Pressure Vessel Shells (A 372 - 53 T):[2]

Section 11.—In Paragraph (*a*) change the present reference to Methods E 8 to refer to Methods A 370.[3] Revise Paragraph (*b*) to read as follows:

> (*b*) The yield strength prescribed in Table III shall be determined by the offset method, using an offset value of 0.2 per cent of the gage length, or by the total extension under load method, using an extension value of 0.005 in. per inch (0.5 per cent).

Section 16(b).—Change the words "and any part of the fracture is more than $\frac{3}{4}$ in. from the center of the gage length" to read "and any part of the fracture is outside of the middle half of the gage length."

Fig. 2.—Replace with a drawing similar to Fig. 6 of Methods A 370.[3]

Tentative Specifications for Seamless Austenitic Steel Pipe for High-Temperature Central-Station Service (A 376 - 54 T):[3]

Table I.—Change the words "identification symbol" to read "grade" here and throughout the specifications. Delete the line presently identified as "Grade."

Section 6.—Revise to read: "The steel shall conform to the chemical requirements prescribed in Table I or to other chemical requirements as specified in the order."

Section 8.—In Paragraph (*a*) change the words "purchaser's inspector" to read "purchaser." Reference a new footnote after the word "lot" to read: "A lot shall consist of the number of lengths specified in Section 8, of the same size and wall thickness from any one heat of steel."

Include the present Paragraph (*c*) in Paragraph (*b*), relettering the present Paragraph (*d*) as Paragraph (*c*).

REVISIONS OF STANDARDS AND REVERSION TO TENTATIVE

The committee recommends reversion to tentative of the following two standards, incorporating the tentative revisions issued October, 1952:

Standard Specifications for Forged or Rolled Steel Pipe Flanges, Forged Fittings, and Valves and Parts for High-Temperature Service (A 105 - 46).[4]

Standard Specifications for Forged or Rolled Steel Pipe Flanges, Forged Fittings, and Valves and Parts for General Service (A 181 - 49).[4]

ADOPTION OF TENTATIVES AS STANDARDS WITHOUT REVISION

The committee recommends that the following ten tentative specifications be approved for reference to letter ballot of the Society for adoption as standard without revision:

Tentative Specifications for:

Mild- to Medium-Strength Carbon-Steel Castings for General Application (A 27 - 52 T),[4]
Quenched Carbon-Steel Joint Bars (A 49 - 53 T),[2]
Low-Carbon Steel Track Bolts and Nuts (A 76 - 49 T),[4]
Structural Steel for Ships (A 131 - 53 T),[2]
Structural Rivet Steel (A 141 - 52 T),[4]
High-Strength Steel Castings for Structural Purposes (A 148 - 50 T),[4]
Heat-Treated Carbon and Alloy Steel Track Bolts and Carbon Steel Nuts (A 183 - 53 T),[2]
Alloy-Steel Castings for Pressure Containing Parts Suitable for High-Temperature Service (A 217 - 49 T),[4]
High Strength Low Alloy Structural Steel (A 242 - 53 T),[2] and
Forged or Rolled Carbon and Alloy Steel Flanges, Forged Fittings, and Valves and Parts for Low-Temperature Service (A 350 - 52 T).[4]

ADOPTION OF TENTATIVE AS STANDARD WITH REVISION

The committee recommends that the Tentative Specifications for Boiler Rivet Steel and Rivets (**A 31 - 52 T**)[4] be approved for reference to letter ballot of the Society for adoption as standard with revisions as follows:

Section 7.—Revise to read as follows:

> 7. (*a*) The test specimen for grade A steel shall stand being bent cold through 180 deg flat on itself without cracking on the outside of the bent portion.
>
> (*b*) The test specimen for grade B steel shall stand being bent cold through 180 deg without cracking on the outside of the bent portion to an inside diameter which shall have a relation to the thickness of the specimen as prescribed in Table II.

New Table.—Add a new Table III incorporating the requirements in the present text to read as shown in the accompanying Table III, renumbering subsequent tables accordingly.

Section 14(b).—Revise to read as follows: "The rivet shank of grade B steel shall stand being bent cold through 180 deg without cracking on the outside of

TABLE III.—BEND REQUIREMENTS.
(Table III, Specifications A 31.)

Specimen Diameter, in.	Ratio of Bend Diameter to Diameter of Specimen
¾ and under	½
Over ¾	1

TABLE IV.—BEND REQUIREMENTS.
(Table V, Specifications A 31.)

Diameter of Rivet Shank, in.	Ratio of Bend Diameter to Diameter of Rivet Shank
¾ in. and under	1
Over ¾ in.	1½

the bent portion as prescribed in Table IV."

New Table.—Add a new Table V incorporating the requirements in the present text to read as shown in the accompanying Table IV.

REVISIONS OF STANDARDS, IMMEDIATE ADOPTION

The committee recommends that the following 18 standards be revised as indicated and accordingly requests the necessary nine-tenths affirmative vote at the Annual Meeting in order that these may be referred to letter ballot of the Society:

Standard Specifications for Electric-Fusion (Arc)-Welded Steel Pipe (Sizes 4 in. and Over) (A 139 – 54):[3]

Section 1.—Delete Note 2.

Table I.—Delete the word "Composition" from the title and revise the table to contain the following requirements:

	Grade A	Grade B
Carbon, max, per cent	...	0.30
Manganese, per cent	0.30 to 1.00	0.30 to 1.00
Phosphorus, max, per cent	0.040	0.040
Sulfur, max, per cent	0.050	0.050

Section 2.—Delete the words "Unless otherwise specified."

Section 3.—Revise to read: "The steel shall conform to the chemical requirements prescribed in Table I."

Section 4.—Change the words "prescribed in Table I for ladle analysis" to read "specified in Section 3."

Section 5.—Revise Paragraph (*a*) to read as follows:

> (*a*) An analysis may be made by the purchaser on samples of pipe selected at random and shall conform to the requirements specified in Section 3. The number of samples shall be determined as follows:

Pipe Size, in.	Number of Samples Selected
Under 14	2 for each lot of 200 pipes or fraction thereof
14 to 36, incl.	2 for each lot of 100 pipes or fraction thereof
Over 36	2 for each 3000 ft or fraction thereof

In Paragraph (*b*) change the words "prescribed in Table I" to read "specified in Section 3." Also delete the words "or the lot shall be rejected."

Section 6(b).—Revise to read "The yield point shall be determined by the drop of the beam, by the halt in the gage of the testing machine, by the use of dividers, or by other approved methods. When a definite yield point is not exhibited, the yield strength corresponding to a limited offset of 0.2 per cent of the gage length of the specimen, or to a total extension of 0.5 per cent of the gage length under load shall be determined."

Section 11.—Revise the title to read: "Production Test Specimens and Methods of Testing." Add a new Paragraph (*a*) to read as follows, relettering the present paragraphs accordingly:

> (*a*) The test specimens and the tests required by these specifications shall conform to those described in the Methods and Definitions for Mechanical Testing of Steel Products (ASTM Designation: A 370).[3]

Standard Specification for Carbon Steel Forgings for General Industrial Use (A 235 – 54):[4]

Section 11.—In Paragraph (*a*) change the reference to Methods E 8 to refer to

Methods A 370 for Mechanical Testing of Steel Products.[3]

Revise Paragraphs (*d*), (*e*), and (*f*) to read as follows:

(*d*) If the yield point is determined by total extension under load, such extension shall be 0.005 in. per inch of gage length (0.5 per cent).

(*e*) The yield strength shall be determined at 0.2 per cent offset or by a total extension under load of 0.005 in. per inch of gage length.

(*f*) The yield point or yield strength shall be determined at a rate of separation of the crossheads under load not to exceed $\frac{1}{16}$ in. per minute per inch of gage length. The tensile strength shall be determined at a rate of separation of the crossheads under load not to exceed $\frac{1}{2}$ in. per minute per inch of gage length.

Section 14(*c*).—Change the words "and any part of the fracture is more than $\frac{3}{4}$ in. from the center of the gage length" to read "and any part of the fracture is outside of the middle half of the gage length."

Table III.—Change column heading "Yield Point, min, psi" to read "Yield Point or Yield Strength, min, psi."

Add a new footnote *d* referenced after the yield point or yield strength requirements for classes C, C1, E, F, and F1 to read "Yield point, see Section 11 (*d*)."

Change the present Footnote *d* and its references after the yield point or yield strength requirements for class G to become footnote *e* and revise to read "Yield strength, see Section 11(*e*)."

Fig. 1.—Replace with a drawing similar to Fig. 6 of Methods A 370.

Standard Specification for Carbon Steel Forgings for Railway Use (A 236 – 54):[3]

Section 1.—At the end of Paragraph (*a*), revise the note to read as follows:

NOTE.—When axles corresponding to the size classification shown in Table II of the Specification for Carbon Steel Axles for Cars and Tenders (ASTM Designation: A 21)[4] are ordered heat treated in accordance with the Notes 1 and 2 in Section 1 of Specification A 21, Sections 10, 11, 13, and 14 of Specification A 21 are applicable thereto.

Section 11.—Revise Paragraphs (*a*), (*d*), (*e*), and (*f*) as described above for Section 11 in Specification A 235.

Section 13.—Change by addition of the underlined words: "When specified under Supplementary Requirement S5, the following microscopic examination of *classes D, E, F, G, and H* forgings shall be made:"

In Item (*3*) of this section change reference to Fig. 2 (*a*) or (*b*) to include the photomicrographs added for classes D and E, and G and H. Also in Item (*3*) delete the last sentence reading: "Only one irregular mesh as large as $\frac{1}{2}$ in. in diameter shall be permitted in a field 3 in. in diameter, as shown on the screen or photomicrograph.

Section 14(*b*).—Change reference to "class F" to include classes D, E, G, and H.

Section 15(*b*).—Revise as indicated above for Section 14 (*c*) in Specification A 235.

Table III.—Change column heading "Yield Point, min, psi" to read "Yield Point or Yield Strength, min, psi."

Add a new Footnote *c* referenced after yield point or yield strength requirements for classes C, D, E, and F to read "Yield point, see Section 11(*d*)."

Change the present Footnote *c* and its references after the yield point or yield strength requirements for classes G and H to become Footnote *d* and revise to read "Yield strength, see Section 11(*e*)."

Figures.—Replace Fig. 1 with a drawing similar to Fig. 6 of Methods A 370.

Delete the present Fig. 2 covering photomicrographs for class F forgings. Add new Fig. 2 covering new photomicrographs for classes D and E, a new Fig. 3 covering new photomicrographs for class F, and a new Fig. 4 covering new photomicrographs for classes G and H. (These photomicrographs will be identical with those in AAR Specification M-126.)

Supplementary Requirements.—In supplementary requirement S5 add reference to classes D, E, G, and H where class F appears alone now.

Standard Specification for Alloy Steel Forgings for General Industrial Use (A 237 - 54):[4]

Section 11.—Revise Paragraphs (*a*), (*d*), and (*f*) as described above for Section 11 in Specification A 235. Revise Paragraph (*e*) to read as follows:

> (*e*) The yield strength shall be determined by the offset method, using an offset value of 0.2 per cent of the gage length, or by the total extension under load method, using an extension value of 0.005 in. per inch (0.5 per cent) for classes D and E, 0.006 in. per inch (0.6 per cent) for classes F and G and 0.007 in. per inch (0.7 per cent) for class H.

Section 13(a) (3).—Delete the words "heat treated" from the first line.

Section 14(b).—Revise as indicated above for Section 14(*c*) in Specification A 235.

Table III.—Change column heading "Yield Point, min, psi" to read "Yield Point or Yield Strength, min, psi."

Add a new Footnote *c* referenced after yield point or yield strength requirements for classes A, B, and C to read "Yield point, see Section 11(*d*)."

Change the present Footnote *c* and its references after the yield point or yield strength requirements for classes D, E, F, G, and H to become Footnote *d* and revise to read "Yield strength, see Section 11(*e*)."

Fig. 1.—Replace with a drawing similar to Fig. 6 of Methods A 370.[3]

Standard Specification for Alloy Steel Forgings for Railway Use (A 238 - 54):[3]

Section 11.—Revise Paragraphs (*a*), (*d*), and (*f*) as described above for Section 11 in Specification A 235. Revise Paragraph (*e*) to read as follows:

> (*e*) The yield strength shall be determined by the offset method, using an offset value of 0.2 per cent of the gage length, or by the total extension under load method, using an extension value of 0.005 in. per inch (0.5 per cent) for classes D and E and 0.006 in. per inch (0.6 per cent) for class F.

Section 15(b).—Revise as indicated above for Section 14(*c*) in Specification A 235.

Table III.—Change column heading "Yield Point, min, psi" to read "Yield Point or Yield Strength, min, psi."

Add a new Footnote *a* referenced after yield point or yield strength requirements for classes A, B, and C to read "Yield point, see Section 11(*d*)."

Change the present Footnote *a* and its references after yield point or yield strength requirements for classes D, E, and F to become Footnote *b* and revise to read "Yield strength, see Section 11(*e*)."

Fig. 1.—Replace with a drawing similar to Fig. 6 of Methods A 370.[3]

Standard Specification for Carbon and Alloy Steel Ring and Disk Forgings (A 243 - 54):[4]

Section 11.—Revise Paragraphs (*a*), (*d*), and (*f*) as described above for Section 11 in Specification A 235. Revise Paragraph (*e*) to read as follows:

> (*e*) The yield strength shall be determined by the offset method, using an offset value of 0.2 per cent of the gage length, or by the total extension under load method, using an extension value of 0.005 in. per inch (0.5 per cent) for classes G, K, and L; 0.006 in. per inch (0.6 per cent) for classes M and N; and 0.007 in. per inch (0.7 per cent) for class O.

Section 14(c).—Revise as indicated above for Section 14(*c*) in Specification A 235.

Table III.—Change column heading "Yield Point, min, psi" to read "Yield Point or Yield Strength, min, psi."

Add a new Footnote *d* referenced after yield point or yield strength requirements for classes C, C1, E, F, F1, H, I, and J to read "Yield point, see Section 11(*d*)."

Reletter the subsequent footnotes and change the present Footnote *d* (relettered Footnote *e*) referenced after classes G, K, L, M, N, and O to read "Yield strength, see Section 11(*e*)."

Fig. 1.—Replace with a drawing similar to Fig. 6 of Methods A 370.[3]

Supplementary Requirement S3.—In Paragraph (*a*) change the words "bent cold" to read "bent at room temperature."

Standard Specifications for Welded and Seamless Steel Pipe Piles (A 252 – 54):[4]

Section 1.—Delete the Note referring to Methods A 370.[3]

Section 3.—Revise Paragraph (*b*) to read:

> (*b*) The yield point shall be determined by the drop of the beam, by the halt in the gage of the testing machine, by the use of dividers, or by other approved methods. When a definite yield point is not exhibited, the yield strength corresponding to a permanent offset of 0.2 per cent of the gage length of the specimen, or to a total extension of 0.5 per cent of the gage length under load, shall be determined.

Section 4.—Retitle to read: "Test Specimens and Methods of Testing," and add a new Paragraph (*a*) to read as follows, relettering subsequent paragraphs accordingly:

> (*a*) The test specimens and the tests required by these specifications shall conform to those described in the Methods and Definitions for the Mechanical Testing of Steel Products (ASTM Designation: A 370).[3]

Standard Specification for Carbon Steel Seamless Drum Forgings (A 266 – 54):[4]

Section 11.—Revise Paragraphs (*a*), (*b*), and (*c*) as indicated above for Section 11(*a*), (*d*), and(*f*) in Specification A 235.

Section 15(b).—Revise as indicated above for Section 14(*c*) in Specification A 235.

Fig. 1.—Replace with a drawing similar to Fig. 6 of Methods A 370.[3]

Section 12.—Change the words "bent cold" to read "bent at room temperature."

Standard Specifications for Seamless and Welded Ferritic Stainless Steel Tubing for General Service (A 268 – 54):[3]

Section 1.—Delete the Note.

Table I.—In Table I and throughout the specifications, change the words "identification symbol" to read "grade."

Section 3.—Delete Paragraphs (*b*) and (*c*).

New Section.—Add a new Section 4 titled "Heat Treatment" to read as follows, renumbering subsequent sections accordingly:

> 4. All material shall be furnished in the heat treated condition unless otherwise agreed between the manufacturer and the purchaser and so specified in the order. This heat treatment shall be performed by a method and at a temperature selected by the manufacturer.

Section 4.—Renumber as Section 5 and revise to read as follows, deleting the present Paragraph (*b*): "The steel shall conform to the chemical requirements prescribed in Table I."

New Section.—Add a new Section 6 titled "Ladle Analysis" to read as follows:

> 6. An analysis of each heat of steel shall be made to determine the percentages of the elements specified in Section 5. The chemical composition thus determined or a report of check analysis as specified in Section 7(*a*) shall be reported to the purchaser or his representative and shall conform to the requirements specified in Section 5.

Section 5.—Renumber as Section 7 and revise to read as follows:

> (*a*) An analysis of either one billet or one length of flat rolled stock or one tube shall be made for each heat of steel. Drillings for analysis

shall be taken from several points around each tube selected for analysis and, if on the flat rolled stock, samples shall be milled from the entire cross section of the stock. When taken from the billet, drillings shall be obtained by drilling parallel to the axis at a point midway between the outside and center of the piece. The chemical composition thus determined shall conform to the requirements specified in Section 5.

(*b*) If the analysis made in accordance with Paragraph (*a*) does not conform to the requirements specified in Section 5, an analysis of each billet or length of flat rolled stock or tube from the same heat may be made, and all billets, stock, or tubes thus conforming to the requirements shall be accepted so far as chemical composition is concerned.

Section 6.—Renumber as Section 8 and revise Paragraph (*b*) to read as indicated above for Section 6(*b*) in Specifications A 139.

Section 8.—Renumber as Section 10 and delete Paragraphs (*a*) and (*e*), relettering the remaining paragraphs accordingly.

Section 10.—Renumber as Section 12 and change the title to read "Test Specimens and Methods of Testing." Add a new Paragraph (*a*) as indicated above for Section 11 in Specifications A 139.

Section 11.—Renumber as Section 13 and change the word "prescribed" to read "specified" in Paragraph (*d*).

Section 13.—Renumber as Section 15 and change the word "prescribed" to read "specified."

Standard Specifications for Seamless and Welded Austenitic Stainless Steel Tubing for General Service (A 269 – 54):[3]

Section 1.—Delete the Note.

Table I.—In Table I and throughout the specifications, change the words "identification symbol" to read "grade." In Table I delete the entire line identified as grade.

Section 3.—Revise the present Paragraphs (*b*) and (*c*) to read as follows:

(*b*) At the manufacturer's option tubing may be furnished either hot finished or cold finished.

(*c*) The tubes shall be pickled free from scale. When bright annealing is used, pickling is not necessary.

New Section.—Add a new Section 4 titled "Heat Treatment" to read as follows:

4. (*a*) All material shall be furnished in heat treated condition unless otherwise agreed between the manufacturer and the purchaser and so specified in the order. This heat treatment shall be performed by a method and at a temperature selected by the manufacturer.

(*b*) If any controlled structural characteristics are required these shall be so specified as to be a guide as to the most suitable heat treatment.

Section 4.—Renumber as Section 5 and revise to read as follows, deleting Paragraph (*b*): "The steel shall conform to the chemical requirements prescribed in Table I."

New Section.—Add a new Section 6 to read as indicated above for new Section 6 in Specification A 268, renumbering subsequent sections accordingly.

Section 5.—Renumber as Section 7 and revise to read as indicated above for Section 5 in Specifications A 268.

Section 7.—Renumber as Section 9 and revise as indicated above for Section 8 in Specifications A 268.

Section 9.—Renumber as Section 11 and revise as indicated above for Section 10 in Specifications A 268.

Section 10.—Renumber as Section 12 and in Paragraphs (*a*) and (*c*) change the word "prescribed" to read "specified."

Section 12.—Renumber as Section 14 and change the word "prescribed" to read "specified."

Section 14.—Renumber as Section 16 and delete Paragraph (*b*).

Standard Specifications for Seamless and Welded Austenitic Stainless Steel Sanitary Tubing (A 270 – 54):[3]

Section 1.—Delete the Note.

Table I.—Delete the word "Composition" from the title. Change the word

"Identification Symbol" to read "Grade" and delete the line now identified as "Grade."

Section 3.—Add a Paragraph (*b*) to read: "At the manufacturer's option, tubing may be furnished either hot finished or cold finished." The present Paragraph (*b*) will be retained as new Section 4.

New Section.—Add a new Section 4 titled "Heat Treatment" to consist of the present Section 3(*b*).

Section 4.—Renumber as Section 5 and revise to read as follows, deleting the present Paragraph (*b*): "The steel shall conform to the chemical requirements prescribed in Table I."

New Section.—Add a new Section 6 titled "Ladle Analysis" to read as follows:

> 6. Analysis of each heat of steel shall be made to determine the percentages of the elements specified in Section 5. The chemical composition thus determined shall be reported to the purchaser or his representative, and shall conform to the requirements specified in Section 5.

Section 5.—Renumber as Section 7 and revise to read as follows:

> (*a*) When requested by the purchaser, analyses of one billet per heat or two lengths of flat rolled stock per heat or two tubes from each heat or from each lot of 250 tubes or fraction thereof shall be made. Drillings for analyses shall be taken from several points around each tube selected for analysis and, if on flat rolled stock, samples shall be milled from the entire cross-section of the stock. Drillings shall be taken from the billet at a point midway between the outside and center of the billet drilling parallel to the axis. The chemical composition thus determined shall conform to the requirements specified in Section 5.
>
> (*b*) If the analysis of one of these test specimens does not conform to the requirements specified in Section 5, an analysis of two billets or two lengths of flat rolled stock from the same heat or an analysis of two tubes from the same lot may be made, each of which shall conform to the requirements specified in Section 5.

Section 9.—Renumber as Section 11 and in Paragraph (*b*) change the word "prescribed" to read "specified."

Standard Specifications for Seamless Austenitic Chromium-Nickel Steel Still Tubes for Refinery Service (A 271 – 54):[3]

Section 1.—Delete the Note.

Table I.—Delete the word "Composition" from the title. Change the words "identification symbol" to read "grade" in Table I and throughout the specification.

Section 3.—Revise Paragraph (*b*) to read: "At the manufacturer's option, tubing may be furnished either hot finished or cold finished." Add a new Paragraph (*a*) to read: "The tubes shall be pickled free from scale. When bright annealing is used, pickling is not necessary."

New Section.—Add a new Section 4 to read as indicated above for new Section 4 in Specifications A 269.

Section 4.—Renumber as Section 5 and revise to read as follows, deleting Paragraph (*b*): "The steel shall conform to the chemical requirements prescribed in Table I."

New Section.—Add a new Section 6 titled "Ladle Analysis" to read as shown above in Specifications A 270.

Section 5.—Renumber as Section 7 and in Paragraphs (*a*) and (*b*) change the words "prescribed in Table I" to read "specified in Section 5."

Section 6.—Renumber as Section 8 and revise Paragraph (*b*) to read as indicated above for Section 6 (*b*) in Specifications A 139.

Section 9.—Delete Paragraph (*b*).

Fig. 1.—Delete this figure.

Section 11.—Renumber as Section 13 and revise Paragraph (*b*) to read as indicated above for new Paragraph (*a*) of Section 11 in Specifications A 139.

Section 16.—Renumber as Section 18 and delete Paragraph (*b*).

Standard Specification for Carbon and Alloy Steel Forgings for Magnetic

Retaining Rings for Turbine Generators (A 288 - 54):[4]

Section 11.—Revise Paragraphs (*a*) and (*c*) as described above for Section 11(*a*) and (*f*) in Specification A 235. Change Paragraph (*b*) to read as follows:

> (*b*) The yield strength prescribed in Table III shall be determined by the offset method, using an offset value of 0.02 per cent of the gage length.

Section 14(*b*).—Revise as indicated above for Section 14(*c*) in Specification A 235.

Fig. 1.—Replace with a drawing similar to Fig. 6 of Methods A 370.[3]

Standard Specification for Alloy-Steel Forgings for Nonmagnetic Coil Retaining Rings for Turbine Generators (A 289 - 54):[4]

Section 10.—Revise Paragraphs (*a*) and (*c*) as described above for Section 11(*a*) and (*f*) in Specification A 235. Revise Paragraph (*b*) as indicated above for Section 11(*b*) in Specification A 288.

Section 13(*b*).—Revise as indicated above for Section 14(*c*) in Specification A 235.

Fig. 1.—Replace with a drawing similar to Fig. 6 of Methods A 370.[3]

Standard Specification for Carbon and Alloy Steel Forgings for Reduction Gears (A 290 - 54):[4]

Section 11.—Revise to read as follows:

> 11. (*a*) The material of classes D and E shall conform to the requirements as to tensile properties prescribed in Table IV when tested in accordance with the latest issue of the Methods and Definitions of Mechanical Testing of Steel Products (ASTM Designation: A 370).[3] The yield strength shall be determined by the offset method, using an offset value of 0.2 per cent of the gage length, or by the total extension under load method, using an extension value of 0.005 in. per inch (0.5 per cent) for class D and 0.006 in. per inch (0.6 per cent) for class E.
>
> (*b*) The yield point or yield strength shall be determined at a rate of separation of the crossheads under load not to exceed $\frac{1}{16}$ in. per minute per inch of gage length. The tensile strength shall be determined at a rate of separation of the crossheads under load not to exceed $\frac{1}{2}$ in. per minute per inch of gage length.

Section 10(*a*).—In the first sentence, after the words "Table III" add "when tested in accordance with the latest issue of the Methods and Definitions for Mechanical Testing of Steel Products (ASTM Designation: A 370).[3]"

Table IV.—Change column heading "Yield Point, min, psi" to read "Yield Strength, min, psi."

Section 14(*b*).—Revise as indicated above for Section 14(*c*) in Specification A 235.

Fig. 1.—Replace with a drawing similar to Fig. 6 of Methods A 370.[3]

Standard Specification for Carbon and Alloy Steel Forgings for Pinions and Reduction Gears (A 291 - 54):[3]

Section 11.—Revise Paragraph (*a*) as indicated above for Section 11(*a*) in Specification A 235.

Revise the first paragraph of Paragraph (*d*) to read as indicated above for Section 11(*d*) in Specification A 235.

Letter the second paragraph of present Paragraph (*d*) as new Paragraph (*e*) and revise to read as follows:

> (*e*) The yield strength shall be determined by the offset method, using an offset value of 0.2 per cent of the gage length, or by the total extension under load method, using an extension value of 0.005 in. per inch (0.5 per cent) for class 3; 0.006 in. per inch (0.6 per cent) for classes 4, 5, and 6; 0.007 in. per inch (0.7 per cent) for class 7; and 0.008 in. per inch (0.8 per cent) for class 8.

Reletter the present Paragraphs (*e*) and (*f*) as (*f*) and (*g*), respectively, and revise the present Paragraph (*e*) as indicated above for Section 11(*f*) in Specification A 235.

Table III.—Change column heading "Yield Point, min, psi" to read "Yield Point or Yield Strength, min, psi."

Add a Footnote *a* referenced after yield point or yield strength requirements for classes 1 and 2 to read "Yield point, see Section 11(*d*)."

Add a Footnote *b* referenced after yield point or yield strength requirements for classes 3, 4, 5, 6, 7, and 8 to read "Yield strength, see Section 11(*e*)."

Fig. 1.—Replace with a drawing similar to Fig. 6 of Methods A 370.[3]

Section 12(a).—Revise as indicated above for Section 10(*a*) in Specification A 290.

Section 15(b).—Revise as indicated above for Section 14(*c*) in Specification A 235.

Standard Specification for Carbon and Alloy Steel Forgings for Turbine Generator Rotors and Shafts (A 292 - 54):[3]

Section 11.—Revise Paragraphs (*a*) and (*c*) as described above for Section 11(*a*) and (*f*) in Specification A 235. Revise Paragraph (*b*) to read as follows:

> (*b*) The yield strength prescribed in Table III for classes 1 to 7, incl, shall be determined by the offset method, using an offset value of 0.02 per cent of the gage length. The yield strength prescribed in classes 8 and 9 shall be determined by the offset method, using an offset value of 0.2 per cent, or by the total extension under load method using an extension value of 0.005 in. per inch (0.5 per cent) for class 8 and 0.006 in. per inch (0.6 per cent) for class 9.

Table III.—In the column heading for yield strength values, delete the parenthetical expression "(0.02 per cent offset)."

Reletter present Footnote *c* as Footnote *b* and revise to read "Offset 0.02 per cent." Reletter present Footnote *b* as Footnote *c* and revise to read "Offset 0.2 per cent."

Section 14(b).—Revise as indicated above for Section 14(*c*) in Specification A 235.

Fig. 1.—Replace with a drawing similar to Fig. 6 of Methods A 370.[3]

Standard Specification for Carbon and Alloy Steel Forgings for Turbine Bucket Wheels (A 294 - 54):[3]

Section 12.—Revise Paragraphs (*a*) and (*c*) as indicated above for Paragraphs 11(*a*) and (*f*) in Specification A 235. Revise Paragraph (*b*) to read as follows:

> (*b*) The yield strength prescribed in Table III shall be determined by the offset method, using an offset value of 0.02 per cent of the gage length.

Section 13(b).—Replace the reference to Method E 10 with a new reference to Methods A 370.[2]

Section 16(b).—Revise as indicated above for Section 14(*c*) in Specification A 235.

Fig. 1.—Replace with a drawing similar to Fig. 6 of Methods A 370.[3]

REAPPROVAL OF STANDARDS

The committee recommends the reapproval of the following three specifications and one method without change:

Standard Specifications for:

Steel Tires (**A 26 - 39**),
Low Carbon Steel Tie Plates (**A 67 - 48**), and
Hot-Worked High-Carbon Steel Tie Plates (**A 241 - 48**).

Standard Methods of:

Magnetic Particle Testing and Inspection of Heavy Steel Forgings (**A 275 - 47**).

Reaffirmation is recommended for the Standard Specification for Wrought Steel Wheels for Electric Railway Service (**A 25 - 48**) with the following editorial changes:

Section 5.—In the second sentence change "test ingot" to read "test specimen."

Section 8.—In Paragraph (*n*) covering thickness of plate and in Paragraph (*o*) covering diameter of hub change "Table of Standard in Appendix II" to read "standard designs of the American Transit Association."

In Paragraph (r_2) covering projection of hub change "Table 1" and "Table 2" to read "standard designs of the American Transit Association."

Appendix II.—Delete Appendix II and the accompanying Tables 1 and 2.

REPORT OF COMMITTEE A-2

ON

WROUGHT IRON*

During 1954 and 1955 there was a rge of standardization activity in Committee A-2. A meeting was held on June 15, 1954, in Chicago, Ill., in conjunction with the Annual Meeting of the Society. Subcommittees I on Tube and Pipe, II on Wrought Iron Bars, Blooms, and Forgings, and III on Plates, Shapes, and Sheets have all been active.

Subcommittee I developed during the past year the Tentative Specifications for Cold-Drawn Wrought Iron Heat-Exchanger and Condenser Tubes (A 382 – 55 T). Discussions in Subcommittees I and II resulted in the other recommendations included in this report.

Recommendations Accepted by the Administrative Committee on Standards

On March 23, 1955, the Administrative Committee on Standards accepted the recommendation of Committee A-2 that the Tentative Specifications for Cold-Drawn Wrought Iron Heat-Exchanger and Condenser Tubes (**A 382 – 55 T**) be published by the Society. The specifications will appear in the 1955 Book of ASTM Standards, Part 1.

Adoption of Tentatives as Standard Without Revision

The committee recommends that the following tentative specifications be approved for reference to letter ballot of the Society for adoption as standard without revision.

Tentative Specification for:

Wrought Iron Plates (**A 42 – 52 T**),[1]
Welded Wrought Iron Pipe (**A 72 – 52 T**),[1]
Staybolt Wrought Iron, Solid (**A 84 – 52 T**),[1] and
Staybolt Wrought Iron, Hollow-Rolled (**A 86 – 52 T**).[1]

Revision of Standard, Immediate Adoption

The committee recommends that the Standard Specifications for Wrought Iron Rolled or Forged Blooms and Forgings (**A 73 – 39**)[1] be revised by deleting all reference to Class B material, and accordingly requests the necessary nine-tenths affirmative vote at the Annual Meeting in order that these revisions may be referred to letter ballot of the Society.

Withdrawal of Standard

Since material covered by the Standard Specifications for Refined Iron Bars (**A 41 – 36**)[1] is no longer being produced, it is recommended that the specifications be withdrawn.

The recommendations in this report have been submitted to letter ballot of the committee, the results of which will be reported at the Annual Meeting.[2]

This report has been submitted to letter ballot of the committee, which consists of 32 voting members; 20 members returned their ballots, of whom 17 have voted affirmatively and 0 negatively.

Respectfully submitted on behalf of the committee,

A. D. Morris,
Chairman

L. S. Crane,
Secretary.

*** Presented at the Fifty-eighth Annual Meeting of the Society. June 26–July 1, 1955.**

[1] **1952 Book of ASTM Standards, Part 1.**

[2] **The letter ballot vote on these recommendations was favorable; the results of the vote are on record at ASTM Headquarters.**

REPORT OF COMMITTEE A-3

ON

CAST IRON*

There were two meetings of Committee A-3 during the past year: in Chicago, Ill., on June 18, 1954, and in Cincinnati, Ohio, on February 3, 1955. Many subcommittee meetings were held in conjunction with the main committee.

A comprehensive report was made orally to Committee A-3 at its February meeting on the progress of the elevated temperature tests upon cast irons at the Southern Research Institute in Birmingham, Ala. This work is under the guidance of the ASTM-ASME Joint Committee on Effect of Temperature on the Properties of Metals. About 80 per cent of the creep rupture tests at 1000 F have been completed. During the past year the oldest specification of Committee A-3 (A 43 for Foundry Pig Iron, first published in 1904) was given a thorough study and was revised as attached to this report.[1]

The committee consists of 127 members, of whom 45 are classified as producers, 50 as consumers, and 32 general interest members.

The committee records with regret the death of A. R. Ellis of the Pittsburgh Testing Laboratory, a long-time member of Committee A-3 and the Society. Another distinguished senior member, G. F. Comstock, Titanium Alloy Division of the National Lead Co., resigned in 1955.

W. L. Collins has resigned as chairman of Subcommittee XI on Methods of Testing and has been replaced by G. A. Timmons of the Climax Molybdenum Co. of Michigan. G. Dinges, Nordberg Mfg. Co., has replaced R. W. Kraft as chairman of Subcommittee XXVI on Low-Temperature Properties of Cast Iron. C. F. Walton, Gray Iron Founders' Society, has accepted the chairmanship of Subcommittee X on Nomenclature and Definitions.

REVISIONS OF TENTATIVES

The committee recommends that the following three tentatives be revised as indicated and continued as tentative:

Tentative Specifications for Foundry Pig Iron (A 43 – 49 T):[2]

The complete revision of these specifications is appended to this report.[1] There have been many changes proposed in the chemical requirements of the various grades of pig iron.

Tentative Specifications for Chilled and White Iron Castings (A 360 – 52 T):[2]

These specifications have been changed to a method of test. The proposed revision is appended.[3]

Tentative Methods of Chill Testing of Cast Iron (A 367 – 53 T):[4]

Section 5.—Change to read as follows, retaining the present Fig. 1.

5. The test specimen shall be broken by striking with a hammer in such a manner that

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* Presented at the Fifty-eighth Annual Meeting of the Society, June 26–July 1, 1955.

[1] The revised specifications appear in the 1955 Book of ASTM Standards, Part 1.

[2] 1952 Book of ASTM Standards, Part 1.

[3] The revised method appears in the 1955 Book of ASTM Standards, Part 1.

[4] 1953 Supplement to Book of ASTM Standards, Part 1.

the fracture is straight and midway of its length. The chilled iron at the apex of the wedge with a few exceptions consists of two zones. That portion nearest the apex entirely free of any gray spots is designated as *clear chill.* That portion starting with the end of the clear chill and continuing to the location where the last spot of cementite or white iron is visible is designated as the *mottled zone.* The extent of the mottled zone may vary from virtually nothing to an amount equal to and even greater than the amount of the clear chill. If the wedge is measured at the junction of the gray fracture with the first appearance of chilled iron, the measurement shall be designated as *total chill.* In all cases, the chill shall be expressed in $\frac{1}{32}$ in. as measured across the wedge at the locations just described. The location of this measurement for a wedge having a narrow mottled zone is shown in Fig. 1. For structure control purposes, it is generally satisfactory to measure the wedge where the structure is approximately 50 per cent white iron and 50 per cent gray iron. This value will be found to be virtually the same as the average of the measurement of the clear chill and the total chill. In reporting the chill measurement, the size of the test specimen shall be designated. A chill reported as W3-12 would indicate that wedge W3 was used and the width at the junction of the chilled and gray portions of the fraction was $\frac{12}{32}$ in.

Section 9.—Change to read as follows:

9. The test specimen shall be broken in such a manner that the fracture is straight and follows the notch in the test specimen. The chill from the chilled face to the first appearance of a gray spot shall be designated as *clear chill.* The distance from the chilled face to the last appearance of a spot of white iron shall be designated as *total chill.* That portion of the chill affected zone between the clear chill and the total chill shall be designated as the *mottled zone.* As in Section 5, it will be found satisfactory for general structure and quality control purposes to measure chill from the chilled face to a location where the structure is approximately 50 per cent white iron which is roughly half-way through the mottled zone. If the chill test is used for the control of iron for castings having a chilled surface for wear resistant purposes, it would be desirable to measure and record clear chill. If the casting with a chilled surface is to have some machining operation in the proximity of the chilled surface, it may also be necessary to specify maximum depth of total chill as well as depth of clear chill. In all cases, the depth of chill shall be expressed in $\frac{1}{32}$ in. and the size of the test specimen used shall be designated. For example, a measurement recorded as 4C-12 indicates that test specimen design 4C was used and the depth of chill was $\frac{12}{32}$ in.

ADOPTION OF TENTATIVES AS STANDARDS WITHOUT REVISION

The committee recommends that the following two specifications be approved for reference to letter ballot of the Society for adoption as standard without revision:

Tentative Specifications for:

Automotive Gray Iron Castings (**A 159 – 49 T**),[2] and

Nodular Iron Castings (**A 339 – 51 T**).[2]

REAPPROVAL OF STANDARDS

The committee recommends that the following seven standards be reapproved and continued as standard without change:

Standard Specifications for:

Cast Iron Soil Pipe and Fittings (**A 74 – 42**),

Gray Iron Castings for Valves, Flanges, and Pipe Fittings (**A 126 – 42**), and

Cast Iron Culvert Pipe (**A 142 – 38**).

Standard Methods of:

Compression Testing of Cast Iron (**A 256 – 46**), and

Impact Testing of Cast Iron (**A 327 – 54**).

Recommended Practices for:

Evaluating the Microstructure of Graphite in Gray Iron (**A 247 – 47**), and

Torsion Tests of Cast Iron (**A 260 – 47**).

STANDARDS CONTINUED WITHOUT REVISION

The following five standards have been published for two years or more without change, and the committee recommends their continuation as standard at this time:

Standard Specifications for:

Gray Iron Castings (**A 48 – 48**),

Lightweight and Thin-sectioned Gray Iron Castings (**A 190 – 47**),

Gray Iron Castings for Pressure-Containing Parts for Temperatures Up to 650 F (**A 278 – 53**), and

Gray Iron Castings for Elevated Temperatures for Non-Pressure Containing Parts (**A 319 - 53**).

Definition of Terms:

Relating to Cast Iron (**A 196 - 47**).

EDITORIAL CHANGES

The committee recommends that the Tentative Specifications for Automotive Gray Iron Castings (**A 159 - 53 T**)[4] be changed editorially as follows:

Appendix.—In Section A4 delete from the suggested uses for alloy No. 120 the words "truck brake drums."

The recommendations in this report have been submitted to letter ballot of the Committee, the results of which will be reported at the Annual Meeting.[5]

ACTIVITIES OF SUBCOMMITTEES

A complete review of the subcommittee activities will not be given but only those which have a direct bearing on present specifications or those which may be of interest to other committees.

Subcommittee I on Pig Iron (H. W. Stuart, chairman) has reached final agreement on the revision of the Tentative Specifications for Foundry Pig Iron (A 43 - 49 T) and has recommended to Committee A-3 that the specifications be revised to read as attached to this report.[1]

Subcommittee XIX on Chilled and White Iron Castings (J. J. Marsalka, chairman) revised the former Tentative Specification for Chilled and White Iron Castings (A 360 - 52 T) to become a Tentative Method of Test for Chilled and White Iron Castings as appended to this report.[3]

Subcommittee XXII on the Elevated Temperature Properties of Cast Iron (J. S. Vanick, chairman) has appointed a special task group to study a stress relief procedure and inspection for the Standard Specifications for Gray Iron Castings for Pressure-Containing Parts for Temperatures up to 650 F (A 278 - 53).

Subcommittee XXIV on Nodular Iron (T. E. Eagan, chairman) has, after due consideration, recommended the advancement to standard without change of the Tentative Specifications for Nodular Iron Castings (A 339 - 51 T).

Subcommittee XXV on Methods of Chill Testing Cast Iron (D. E. Krause, chairman) has been studying the provisions for measurement of chill in the Tentative Methods of Chill Testing of Cast Iron (A 367 - 53 T). As a result of this study revisions have been proposed and are explained in this report.

This report has been submitted to letter ballot of the committee, which consists of 126 voting members; 70 members returned their ballots, of whom 69 have voted affirmatively and 1 negatively.

Respectfully submitted on behalf of the committee,

H. W. STUART,
Chairman.

T. E. EAGAN,
Secretary.

EDITORIAL NOTE

Subsequent to the Annual Meeting, Committee A-3 presented to the Society through the Administrative Committee on Standards the following recommendations:

Tentative Specifications for:

High-Strength Nodular Iron Castings (A 396 - 55 T), and
Cast Nodular Iron for Pressure Containing Parts for Use at Elevated Temperatures (A 395 - 55 T).

These recommendations were accepted by the Standards Committee on September 15, 1955, and the new specifications are available as separate reprints.

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[5] The letter ballot vote on these recommendations was favorable; the results of the vote are on record at ASTM Headquarters.

REPORT OF COMMITTEE A-5
ON
CORROSION OF IRON AND STEEL*

Committee A-5 on Corrosion of Iron and Steel held two meetings during the year: on June 16, 1954, at Chicago, Ill., and on February 1, 1955, at Cincinnati, Ohio.

The committee now consists of 112 members, of whom 49 are classified as producers, 35 as consumers, and 28 as general interest members.

RECOMMENDATIONS ACCEPTED BY THE ADMINISTRATIVE COMMITTEE ON STANDARDS

Subsequent to the 1954 Annual Meeting, Committee A-5 presented to the Society through the Administrative Committee on Standards the following recommendations:

Tentative Specifications for:

Zinc Coating (Hot Dip) on Assembled Steel Products (**A 386 - 55 T**),

Tentative Recommended Practices for:

Safeguarding Against Warpage and Distortion During Hot-Dip Galvanizing of Steel Assemblies (**A 384 - 55 T**), and

Tentative Recommended Practices and Design Suggestions for:

Providing High Quality Zinc Coatings (Hot Dip) on Assembled Products (**A 385 - 55 T**).

These recommendations were accepted by the Standards Committee on March 23, 1955.

NEW TENTATIVE

The committee recommends for publication as tentative the Specification for Zinc-Coated Steel Chain-Link Fence Fabric as appended hereto.[1] This specification combines in one specification requirements for chain-link fence galvanized either before weaving or after weaving. It will replace Standard Specification for Chain-Link Fence Galvanized After Weaving (A 117 - 33) and Tentative Specification for Chain-Link Fence Galvanized Before Weaving (A 337 - 51 T).

REVISIONS OF TENTATIVES

The committee recommends that the following specifications be revised as indicated and continued as tentative:

Tentative Specification for Zinc-Coated (Galvanized) Iron or Steel Sheets, Coils and Cut Lengths (A 93 - 53 T),[2] revised as appended hereto.[3]

Tentative Specification for 1.25-oz Class Coating (Pot Yield) Zinc-Coated (Galvanized) Iron or Steel Roofing Sheets (A 361 - 52 T),[4] revised as appended hereto.[3]

Tentative Specification for Overhead Ground Wire Strand (A 363 - 52 T):[4]

Section 1.—Change to read as follows:

1. These specifications cover High-Strength, Extra-High-Strength, and Utilities grades of concentric lay steel wire strand composed of three wires or seven wires with Class A, Class B or Class C zinc coatings specifically intended for

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* Presented at the Fifty-eighth Annual Meeting of the Society, June 26–July 1, 1955.

[1] The new tentative appears in the 1955 Book of ASTM Standards, Part 1.

[2] 1953 Supplement to Book of ASTM Standards, Part 1.

[3] The revised specification appears in the 1955 Book of ASTM Standards, Part 1.

[4] 1952 Book of ASTM Standards, Part 1.

use as overhead ground wires or static wires for electric power transmission lines.

Section 2.—Revise to read as follows:

2. Orders for strand purchased under these specifications shall include the following information:

(*1*) Quantity of each size,

(*2*) Size and grade of strand (Table II), and

(*3*) Class of zinc coating (Section 8 and Table I).

Section 10(a).—Revise to read as follows:

10.(*a*) The elongation of the strand in 24 in., determined as specified in Paragraph (*b*), shall be not less than 5 per cent for the High Strength and for the 5/16 in., 3-wire Utilities grades, and 4 per cent for the Extra Strength and for the 3/8 in., 7-wire Utilities grades.

Table II.—Revise as shown in the accompanying Table I.

Table III.—Revise as shown in the accompanying Table II.

REVISION OF STANDARD AND REVERSION TO TENTATIVE

The committee recommends that Standard Specification for Zinc-Coated (Galvanized) Iron or Steel Tie Wires (**A 112 – 33**)[4] be revised as appended hereto[3] and reverted to tentative status.

REAPPROVAL OF STANDARDS

The committee recommends continuing without change the following standards:

Standard Specification for Farm-Field and Railroad Right-of-Way Fencing (**A 116 – 48**). The specification is under study for possible revision next year.

Standard Specification for Barbed Wire (**A 121 – 48**). This specification is also under study for revision in the near future.

Standard Method of Test for Uniformity of Coating by the Preece Test (Copper Sulfate Dip) on Zinc Coated (Galvanized) Iron or Steel Articles (**A 239 – 41**)

Standard Recommended Practice for Safeguarding Against Embrittlement of Hot Galvanized Structural Steel Products and Procedure for Detecting Embrittlement (**A 143 – 46**).

The committee recommends the continuation as tentative of the Specification for Long Terne Iron or Steel Sheets, Coils and Cut Lengths (**A 308 – 50 T**). A study is under way to revise the sampling procedure and coating weight classification and possibly to standardize this specification next year.

TABLE I.—PHYSICAL PROPERTIES OF ZINC COATED STEEL OVERHEAD GROUND WIRE STRAND.
(Revision of Table II, Specification A 363.)

Nominal Diameter of Strand, in.	Number of Wires in Strand	Nominal Diameter of Coated Wire in Strand, in.	Approximate Weight of Strand, lb per 1000 ft	Minimum Breaking Strength of Strand, lb		
				High Strength Grade	Extra High Strength Grade	Utilities Grade
5/16	3	0.145	171	. . .	. . .	6 500
5/16	7	0.104	205	8 000	11 200	. . .
3/8	7	0.120	273	10 800	15 400	11 500
7/16	7	0.145	399	14 500	20 800	. . .
1/2	7	0.165	517	18 800	26 900	. . .

TABLE II.—RANGE OF STRAND LENGTHS PER REEL FOR AT LEAST 95 PER CENT OF THE COMPLETED STRAND.
Revision of Table III, Specification A 363.)

Nominal Diameter of Strand, in.	Number of Wires in Strand	Length in Feet of Strand Per Reel for at Least 95 per cent of the Order	
		Min	Max
5/16	3	4700	7900
5/16	7	4800	7700[a]
3/8	7	3600	5800[a]
7/16	7	4700	7900
1/2	7	3600	6100

[a] Purchasers may procure maximum lengths up to 12,000 ft for $\frac{5}{16}$-in. diameter strand and up to 9400 ft for $\frac{3}{8}$-in. diameter strand.

WITHDRAWAL OF TENTATIVE AND STANDARD

The committee recommends the withdrawal of the Standard Specification for Chain-Link Fence Galvanized After Weaving (**A 117 – 33**)[4] and the Tentative Specification for Chain-Link Fence Galvanized Before Weaving (**A 337 – 51 T**).[4] These specifications are to be replaced by the new Tentative Specification for Zinc-Coated Steel Chain-Link Fence Fabric referred to previously in the report.

The recommendations in this report have been submitted to letter ballot of the committee, the results of which will be reported at the Annual Meeting.[5]

EDITORIAL REVISIONS

The committee recommends as an editorial change the inclusion of a note as given below in the following specifications:

Specifications for:

Zinc-Coated (Galvanized) "Iron" Telephone and Telegraph Line Wire (**A 111 - 52**),[4]
Zinc-Coated (Galvanized) Iron or Steel Tie Wires (**A 112 - 33**),[4]
Zinc-Coated Steel Wire Strand ("Galvanized" and Class A ("Extra Galvanized")) (**A 122 - 54 T**),[6]
Zinc-Coated Steel Wire Strand (Class B and Class C Coatings) (**A 218 - 54 T**),[6]
Zinc-Coated Steel Overhead Ground Wire Strand (**A 363 - 52 T**),[4] and
Zinc-Coated (Galvanized) High Tensile Steel Telephone and Telegraph Line Wire (**A 326 - 52**).[4]

New Note.—Add the following Note to the sections on Adherence of Coating:

Note.—Loosening or detachment during the Adhesion Test of superficial, small particles of zinc formed by mechanical polishing of the surface of zinc-coated wire shall not be considered cause for rejection.

ACTIVITIES OF SUBCOMMITTEES

Subcommittee VII on Methods of Test (O. B. Ellis, chairman) is investigating nondestructive methods for the determination of thickness of metallic coating.

Subcommittee XI on Sheet Specification (E. F. Lundeen, chairman) has revised Tentative Specifications for Zinc-Coated (Galvanized) Iron or Steel Sheets, Coils and Cut Lengths (A 93 - 53 T) and for 1.25-oz Coating (Pot Yield) Zinc-Coated (Galvanized) Iron or Steel Roofing Sheets (A 361 - 52 T). The subcommittee has also recommended continuance as tentative of the present Tentative Specification for Long Terne Iron or Steel Sheets, Coils and Cut Lengths (A 308 - 53 T), which is under study for revision of the sampling procedure.

Subcommittee XII on Wire Specifications (J. F. Occasione, chairman) prepared the revision referred to earlier in the report of the Specifications for Zinc-Coated (Galvanized) Steel Tie Wires (A 112 - 33), Specifications for Overhead Ground Wire Strand (A 363 - 52 T), and the proposed Tentative Specifications for Zinc-Coated Steel Chain-Link Fence Fabric to replace both A 117 - 33 and A 33 - 51 T which covered chain-link fence fabric galvanized after weaving and galvanized before weaving, respectively. The subcommittee is studying revision of several specifications. Standard Specification for Barbed Wire (A 121 - 48) is to be reviewed for inclusion of requirements relative to splices, lengths, basis of purchase clause, and for possible deletion of Preece test requirements. An investigation is underway regarding modification of coil weight requirements in Specification for High-Strength Telephone Line Wire (A 326 - 52). Standard Specification for Farm-Field and Railroad Right-of-Way Wire Fencing (A 116 - 48) is to be reviewed for inclusion of requirements relative to splices in joints, requirements for size $14\frac{1}{2}$ gage wire, clarification of sampling and testing, basis of purchase clauses, and possible deletion of Preece test requirements.

Subcommittee XIII on Hardware Specifications (B. J. Barmack, chairman) prepared the specifications on galvanizing assembled steel products; and recommended practices for safeguarding against warpage, and for design suggestions to get good galvanizing, mentioned earlier in this report. The subcommittee has under study the matter of the zinc-coating on hardware, shapes, bolts, and such items as are used for steel transmission towers with the view to specifying increased weight of coating as soon as this is commercially practicable. At present it is the subcommittee's conclusion that without special steels or special treatment heavier coatings are not consistently obtainable.

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[5] The letter ballot vote on these recommendations was favorable; the results of the vote are on record at ASTM Headquarters.

[6] 1954 Supplement to Book of ASTM Standards, Part 1.

Subcommittee XIV on Sheet Tests (C. P. Larrabee, chairman) makes detailed reports of its inspection activities in the even numbered years. The atmospheric tests of corrugated sheets at State College, Pa., and Altoona, Pa., were inspected on April 19, 1955.

Sheet TAH (bottom), one of the two remaining unperforated 22-gage galvanized sheets at Altoona, was found to be broken due to mechanical damage and was discarded from the test.

Sheet KAA (bottom) will be removed from the roof of the Juniata Shop and re-exposed on the roof of the Pennsylvania Railroad Laboratory in Altoona. This is necessary because of a reroofing program.

Two errors were found in Table III of the 1954 Report. Sheets TAX (bottom) and SAW (bottom) were erroneously reported to have shown "first rust." The corrected table, including the results of the 1955 and 1956 inspections, will be published next year.

The subcommittee is cooperating with the American Welding Society in the inspection of metallized coatings of zinc and aluminum on steel panels which are exposed to atmospheric corrosion at the ASTM test sites.

Subcommittee XV on Wire Tests (F. M. Reinhart, chairman) has continued with regular annual inspections of the wire and wire products in the exposure tests. The detailed report on its findings is appended hereto.[7]

Subcommittee XVI on Hardware Tests (A. Mendizza, chairman) has completed its plans for a new test on hardware, involving atmospheric exposure tests at New York City and Kure Beach, N. C., of zinc and aluminum coatings on carbon and alloy steels. The subcommittee has continued inspection of hardware exposed several years ago. The report of these inspections is appended hereto.[8]

This report has been submitted to letter ballot of the committee, which consists of 112 members; 110 members returned their ballot, of whom 100 have voted affirmatively and 0 negatively.

Respectfully submitted on behalf of the committee,

A. P. Jahn,
Chairman.

C. P. Larrabee,
Secretary.

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[7] See p. 124.

[8] See p. 149.

REPORT OF SUBCOMMITTEE XV ON ATMOSPHERIC EXPOSURE TESTS OF WIRE AND WIRE PRODUCTS

(COVERS 1953 AND 1954 INSPECTIONS)

This report summarizes the results of the atmospheric corrosion tests on wire and wire products through 1954 and presents in detail the data from 1953 and 1954 inspections. Reference to earlier reports of Committee A-5 on Corrosion of Iron and Steel which appeared in the Society's *Proceedings* for 1937, 1939, 1941, 1943, 1945, 1947, 1949, 1951, and 1953 will be helpful in studies of these data. These earlier reports contain descriptions of the test methods, micrographs, and other characterizations of specimens in the test as well as the data assembled during previous inspections.

The materials under test are mostly bare and zinc-coated steel wires and wire products, but copper-covered and lead-coated steel wires and chromium and chromium-nickel steel wires are also included. The coatings are expressed in weight terms of ounces per square foot of surface. For comparisons of coating thickness, 1 oz per sq ft of surface may be considered as averaging 0.0017 in. thick for zinc coatings, 0.0013 in. thick for copper coatings, and 0.0010 in. thick for lead coatings.[1]

Specimens of wire and wire products have been exposed for about 18 yr at eleven sites. The locations of these sites and their atmospheres are as follows:

Test Location	General Type of Atmosphere	Remarks
Pittsburgh, Pa. (abandoned)	Severe industrial	On Brunot Island in the Ohio River about 2 miles west of the city
Bridgeport, Conn.	Industrial	In the city
Sandy Hook, N. J. (abandoned)	Seacoast	About 300 yd from the Atlantic Ocean
Santa Cruz, Calif.	Rural (marine)	About 3 miles from the Pacific Ocean
State College, Pa.	Rural	Central Pennsylvania
Lafayette, Ind.	Rural	Wabash River Valley
Ames, Iowa	Rural	Central Iowa
Manhattan, Kans.	Rural	Kansas River Valley
Ithaca, N. Y.	Rural	Central New York
College Station, Tex.	Rural	About 120 miles inland
Davis, Calif.	Rural	About 80 miles inland

The Pittsburgh, Pa., and Sandy Hook, N. J., sites were abandoned in 1951 and 1952, respectively.

At each location, more than 900 specimens were exposed. These included short lengths of wire (42 in. long) and wire strand at all locations, farm field fence at nine sites, and barbed wire and chain link fence at eight locations.

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[1] The lead-coated wires in these tests were lead coated over a bonding coat of zinc. See *Proceedings*, Am. Soc. Testing Mats., Vol. 43, p. 87 (1943) for analysis of lead coatings.

The extent of corrosion is being measured by weight losses, by visual examination of all specimens at the test sites, and by tension tests on wire specimens. The Bridgeport, Conn., State College, Pa., and Pittsburgh, Pa., specimens were inspected by a traveling committee. Inspections were made at the other exposure locations by the university people in charge of the exposure plots.

Findings from Weight Loss Specimens:

At the start of the program, zinc-coated wire specimens were exposed at Pittsburgh, Pa., Sandy Hook, N. J., and State College, Pa., to determine the rate of loss of coating. These tests have now been completed, and results are summarized in the 1947 report. The over-all average annual loss of coating in ounces per square foot of surface was 0.369 at Pittsburgh, Pa.; 0.117 at Sandy Hook, N. J.; and 0.060 at State College, Pa.

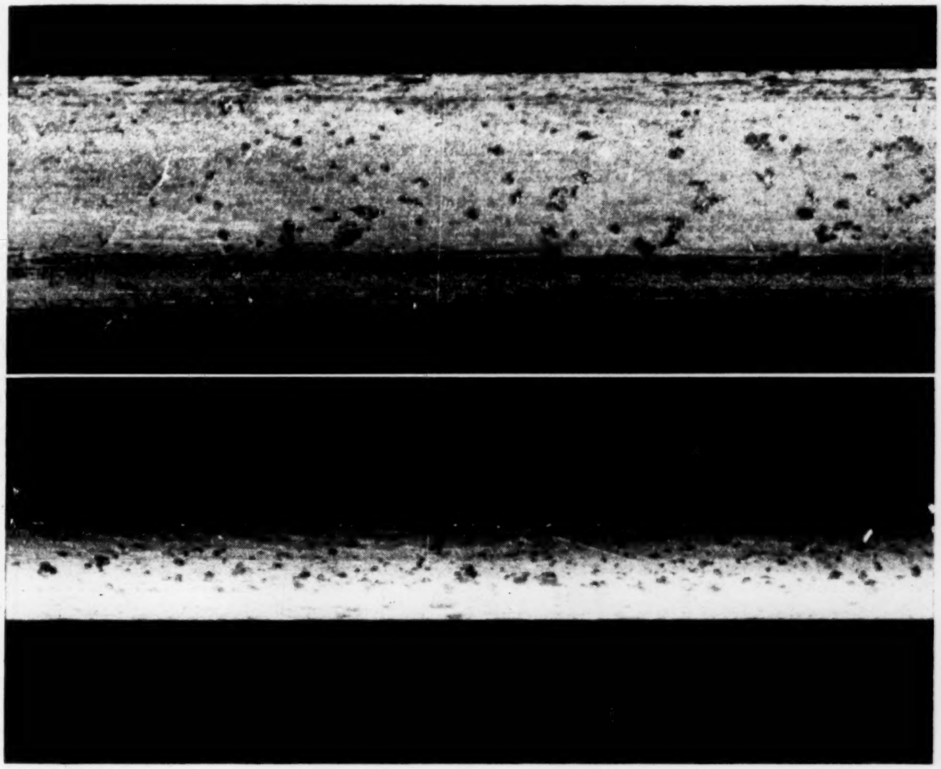

FIG. 1.—Character of Rust on Cold-Drawn 12 to 14 per cent Chromium Stainless Steel Wires After 17.8 yr of Exposure at Lafayette, Ind. Top, wire lot No. 004; bottom, wire lot No. 005 (× 10.)

Findings from Visual Examination for Corrosion at the Exposure Locations:

The condensed and summarized inspection results of corrosion through 1954 are shown in Table A. In this table are shown the average number of years until first rust and until 100 per cent rust appeared on all specimens of each group where progress of rusting has been sufficient to determine the values at the

TABLE A.—REPORT OF GROUP AVERAGES THROUGH 1954—18-YR EXPOSURE.

Abbreviations and symbols used to designate appearance or state of corrosion: M = metallic; G = gray; Y = yellowed, or rust-stained, but not showing actual rough rust of base metal; R = rough rust of base metal; PHR, PHY = rust or yellowed in pinholes; asterisk (*) = speckled appearance of rust, or yellowing; Br, Gn, respectively, signify corroded to a brown or green appearance; MG = intermediate between M and G; GY = predominantly gray but showing indication of Y; SR, SY = superficial R and Y. Tr signifies trace of rust. Figures preceding R (as 5, 20, 50, 100) are percentages. Italicized readings are for those groups which as a group have not reached 1R or 100R.

Coating Group or Weight of Zinc, oz per sq ft of surface	Number in Group	Bridgeport, Conn.		State College, Pa.		Lafayette, Ind.		Ithaca, N. Y.		Ames, Iowa		Manhattan, Kans.		College Station, Tex.		Santa Cruz, Calif.		Davis, Calif.	
		Average of Observed Years of Exposure Until 1R and 100R or State of Corrosion after Approximately 18-yr Exposure																	
		1R	100R	1R	100R	1R	100R	1R	100R	1R	100R	1R	100R	1R	100R	1R	100R	1R	100R
UNFABRICATED WIRES[a]																			
0.20 to 0.30	6	2.1	2.8	5.1	6.2	4.6	5.6	5.6	6.2	6.3	7.5	10.4	*86R*	8.5	12.8	12.6	*99R*	12.3	*53R*
0.25 to 0.35	8	2.3	3.5	4.9	6.7	4.8	6.3	5.6	7.3	6.9	9.3	10.3	*50R*	9.0	*89R*	12.3	*61R*	*36R*	
0.35 to 0.45	7	2.9	3.7	6.6	8.4	5.5	6.8	6.7	8.3	8.4	11.4	*5R*		11.5	*42R*	12.8	*16R*	*GY*	
0.45 to 0.55	10	3.8	5.6	7.9	10.3	7.1	9.2	8.3	10.4	10.7	*99R*	*GY*		12.8	*5R*	13.0	*GY*	*GY*	
0.50 to 0.60	5	4.7	5.7	9.5	11.7	8.5	10.0	9.3	11.2	12.1	*98R*	*GY*		*1R*		*GY*		*G*	
0.60 to 0.70	12	5.4	7.1	10.2	13.2	8.8	11.4	10.4	13.0	*51R*		*GY*		*2R*		*GY*		*G*	
0.70 to 0.85	10	5.7	7.1	11.3	14.3	9.8	11.9	11.1	13.3	*51R*		*GY*		*1R*		*G*		*G*	
0.80 to 1.00	11	6.8	8.9	*87R*		11.5	*97R*	*90R*		*11R*		*GY*		*TrR*		*G*		*G*	
1.20 to 1.35	2	9.0	11.5	*1R*		16.5	*53R*	*31R*		*4R*		*MG*		*G*		...		...	
1.60 to 1.80	11	11.8	*98R*	*TrR*		*1R*		*2R*		*G*		*MG*		*G*		*MG*		*MG*	
2.70 to 3.00	3	*G*		*G*		*G*		*G*		*G*		*MG*		*G*		*MG*		*MG*	
Cu Coat	2	*Gn*		*Gn*		*Gn*		*Gn*		*Br*		*Br*		*Br*		*Br*		*Br*	
Pb Coat	4	*Y*		*100PHR+Y*		*10PHR+Y*		*16R+Y*		*43R*		*8R+PHY*		*2R+Y*		*35SR*		*31SR*	
12–14% Cr	6	*Y*		*G*		*R**		*SY*		*SY*		*M*		*4R+Y*		*4R+65SR*		*7R+38SR*	
18% Cr–8% Ni	3	*MG*		*M*		*M*		*M*		*SY*		*M*		*GY*		*MG*		*MG*	

WIRE STRAND									
0.69 to 0.93	4	9.9 15.3	*GY*	15.0 *10R*	*3R*	*G*	*MG*	*G*	*G*	*G*
1.03 to 1.17	3	16.5 *58R*	*GY*	*3R*	*TrR*	*G*	*MG*	*G*	*MG*	*MG*
1.32 to 1.51	4	*32R*	*GY*	*GY*	*GY*	*G*	*MG*	*G*	*G*	*MG*
1.71 to 2.47	1	*G*	*G*	*G*	*G*	*G*	*MG*	*G*	*MG*	*MG*
Pb Coat	1	*Y*	*100PHR+Y*	*25PHR+Y*	*15R*	*63R*	*15R*	*10PHR*	*68SR*	*10R*
CHAIN LINK FENCE										
0.29 to 0.52[b]	3	2.9 4.8	6.4 9.1	5.7 9.0	5.9 11.5	No Specimens Exposed	No Specimens Exposed	No Specimens Exposed	*39R*	*24R*
1.13 to 1.22[b]	2	8.9 12.0	14.5 *25R*	14.0 *70R*	*39R*				*MG*	*MG*
2.09 to 2.92[b]	2	*GY*	*1R*	*G*	*G*				*MG*	*MG*
1.40 to 1.97[c]	10	9.9 13.0	*2R*	15.5 *17R*	*17R*				*G*	*MG*
4.21[c]	1	*GY*	*GY*	*GY*	*Y*				*MG*	*MG*
Cu Coat	1	*Gn*	*Gn*	*Gn*	*Gn*				*Br*	*Br*
Pb Coat	1	*Y*	*100PHR+Y*	*20PHR*	*18R*				*35SR*	*35SR*
18% Cr–8% Ni	1	*MG*	*M*	*MG*	*M*				*MG*	*MG*

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[a] Farm field fence and barbed wire made from these same wire lots corrode at about the same rate as the unfabricated wire, except that in the case of farm field fence the bottom part of the fence corrodes less than the upper part; in the case of barbed wire, the barbs show rust a year or two before rust appears on the main wire.

[b] Coated before weaving.

[c] Coated after weaving.

TABLE I.—REPORT OF 1953 AND 1954 INSPECTIONS OF UNFABRICATED WIRE SPECIMENS.

Abbreviations and symbols used to designate appearance or state of corrosion: M = metallic; G = gray; Y = yellowed, or rust stained, but not showing actual rough rust of base metal; R = rough rust of base metal; PHR, PHY = rust or yellowed in pinholes; asterisk (*) = speckled appearance of rust or yellowing; SR, SY = superficial R or Y; Br, Gn, respectively, signify corroded to a brown or green appearance; MG = intermediate between M and G; GY = predominately gray but showing indication of Y. Figures preceding R (as 5, 20, 50, 100) are percentages.

Coating Group	Average Coating oz per sq. ft. of Surface[a]	Wire No.	Bridgeport, Conn.		State College, Pa.		Lafayette, Ind.		Ithaca, N. Y.		Ames, Iowa		Manhattan, Kans.		Santa Cruz, Calif.		College Station, Texas		Davis, Calif.	
			16.5 Yr.	17.5 Yr.	16.3 Yr.	17.3 Yr.	17.0 Yr.	18.0 Yr.	16.9 Yr.	17.9 Yr.	16.8 Yr.	17.8 Yr.	16.9 Yr.	17.9 Yr.	16.8 Yr.	17.8 Yr.	16.8 Yr.	17.8 Yr.	16.8 Yr.	17.8 Yr.
0.20	0.27	512	100R	100R	100R	100R	100R	100R	100R	100R	100R	100R	75R	100R	100R	100R	100R	100R	100R	100R
to	0.30	410	100R	100R	100R	100R	100R	100R	100R	100R	100R	100R	100R	100R	100R	100R	100R	100R	99R	99R
0.30	0.28	411	100R	100R	100R	100R	100R	100R	100R	100R	100R	100R	30R	53R	84R	98R	100R	100R	6R	6R
Avg.	0.29	510	100R	100R	100R	100R	100R	100R	100R	100R	100R	100R	50R	86R	100R	100R	100R	100R	9R	17R
0.28	0.29	412	100R	100R	100R	100R	100R	100R	100R	100R	100R	100R	32R	75R	64R	98R	100R	100R	4R	7R
	0.24	511	100R	100R	100R	100R	100R	100R	100R	100R	100R	100R	74R	100R	100R	100R	100R	100R	64R	89R
0.25	0.25	315	100R	100R	100R	100R	100R	100R	100R	100R	100R	100R	72R	65R	98R	100R	100R	100R	99R	99R
to	0.28	215	100R	100R	100R	100R	100R	100R	100R	100R	100R	100R	80R	72R	78R	84R	100R	100R	81R	81R
0.35	0.27	117	100R	100R	100R	100R	100R	100R	100R	100R	100R	100R	64R	67R	59R	79R	100R	100R	39R	33R
Avg.	0.38	317	100R	100R	100R	100R	100R	100R	100R	100R	100R	100R	G	GY	GY	GY	14R	16R	G	G
0.30	0.36	217	100R	100R	100R	100R	100R	100R	100R	100R	100R	100R	56R	74R	29R	46R	100R	100R	2R	2R
	0.32	316	100R	100R	100R	100R	100R	100R	100R	100R	100R	100R	17R	29R	35R	41R	31R	100R	2R	3R
	0.30	216	100R	100R	100R	100R	100R	100R	100R	100R	100R	100R	6R	16R	25R	38R	48R	93R	1R	1R
	0.25	115	100R	100R	100R	100R	100R	100R	100R	100R	100R	100R	74R	79R	96R	98R	100R	100R	51R	66R
0.35	0.36	520	100R	100R	100R	100R	100R	100R	100R	100R	100R	100R	1R	6R	76R	90R	100R	100R	1R	1R
to	0.35	422	100R	100R	100R	100R	100R	100R	100R	100R	100R	100R	GY	GY	1R	2R	14R	18R	GY	G
0.45	0.31	423	100R	100R	100R	100R	100R	100R	100R	100R	100R	100R	1R	10R	GY	5R	20R	25R	GY	GY
Avg.	0.44	522	100R	100R	100R	100R	100R	100R	100R	100R	100R	100R	GY	GY	GY	2R	21R	23R	G	G
0.38	0.37	282	100R	100R	100R	100R	100R	100R	100R	100R	100R	100R	GY	GY	GY	GY	16R	27R	G	GY
	0.38	521	100R	100R	100R	100R	100R	100R	100R	100R	100R	100R	GY	GY	GY	5R	29R	43R	GY	GY
	0.47	421	100R	100R	100R	100R	100R	100R	100R	100R	100R	100R	19R	21R	GY	7R	34R	57R	GY	GY
0.45	0.44	325	100R	100R	100R	100R	100R	100R	100R	100R	100R	100R	GY	GY	GY	GY	GY	GY	G	G
to	0.50	228	100R	100R	100R	100R	100R	100R	100R	100R	100R	100R	GY	GY	GY	GY	GY	1R	G	GY
0.55	0.54	329	100R	100R	100R	100R	100R	100R	100R	100R	94R	99R	GY	GY	GY	GY	14R	11R	G	GY
Avg.	0.52	227	100R	100R	100R	100R	100R	100R	100R	100R	99R	100R	GY	GY	GY	GY	GY	GY	G	GY
0.47	0.41	125	100R	100R	100R	100R	100R	100R	100R	100R	100R	100R	GY	GY	GY	GY	26R	26R	1R	GY
	0.54	127	100R	100R	100R	100R	100R	100R	100R	100R	100R	100R	GY	GY	GY	GY	5R	5R	G	G
	0.38	326	100R	100R	100R	100R	100R	100R	100R	100R	100R	100R	G	GY	GY	GY	1R	3R	G	G
	0.45	226	100R	100R	100R	100R	100R	100R	100R	100R	87R	95R	GY	GY	GY	GY	1R	3R	G	GY
	0.47	327	100R	100R	100R	100R	100R	100R	100R	100R	100R	100R	GY	GY	GY	GY	GY	GY	G	G
	0.45	225	100R	100R	100R	100R	100R	100R	100R	100R	99R	99R	G	GY	GY	GY	GY	GY	G	G
0.50	0.61	530	100R	100R	100R	100R	100R	100R	100R	100R	100R	100R	MG	MG	MG	MG	G	G	MG	MG
to	0.57	432	100R	100R	100R	100R	100R	100R	100R	100R	100R	100R	MG	MG	MG	MG	G	G	MG	MG
0.60	0.60	531	100R	100R	100R	100R	100R	100R	100R	100R	100R	100R	G	G	G	G	G	GY	G	G
Avg.	0.48	431	100R	100R	100R	100R	100R	100R	100R	100R	100R	100R	GY	GY	GY	GY	GY	GY	G	G
0.56	0.54	430	100R	100R	100R	100R	100R	100R	100R	100R	80R	91R	G	G	GY	GY	5R	3R	G	G

0.60 to 0.70 Avg. 0.65	0.69	338	100R	100R	99R	100R	100R	100R	100R	100R	G	6R	MG	MG	MG	MG	G	G	MG	MG
	0.68	236	100R	100R	100R	100R	100R	100R	100R	100R	9R	59R	MG	MG	MG	MG	G	G	MG	MG
	0.61	335	100R	100R	100R	100R	100R	100R	100R	100R	99R	99R	G	GY	GY	GY	G	1R	G	G
	0.63	237	100R	100R	100R	100R	100R	100R	100R	100R	40R	64R	MG	GY	MG	MG	GY	GY	MG	MG
	0.74	135	100R	100R	100R	100R	100R	100R	100R	100R	4R	16R	G	GY	G	G	G	GY	G	G
	0.57	337	100R	100R	100R	100R	100R	100R	100R	100R	89R	100R	GY	GY	GY	GY	11R	8R	GY	GY
	0.67	235	100R	100R	100R	100R	100R	100R	100R	100R	G	1R	GY	GY	GY	GY	GY	GY	G	G
	0.65	239	100R	100R	100R	100R	100R	100R	100R	100R	5R	16R	GY	GY	GY	GY	GY	3R	G	G
	0.67	138	100R	100R	100R	100R	100R	100R	100R	100R	10R	35R	GY	GY	GY	GY	5R	5R	G	GY
	0.64	139	100R	100R	100R	100R	100R	100R	100R	100R	26R	46R	GY	3R	GY	GY	5R	7R	G	GY
	0.66	336	100R	100R	100R	100R	100R	100R	100R	100R	38R	73R	GY	GY	GY	GY	GY	2R	G	G
	0.60	238	100R	100R	100R	100R	100R	100R	100R	100R	77R	94R	GY	GY	GY	GY	GY	3R	G	G
0.70 to 0.85 Avg. 0.75	0.70	540	100R	100R	100R	100R	100R	100R	100R	100R	79R	91R	MG	MG	MG	MG	G	G	MG	MG
	0.72	442	100R	100R	100R	100R	100R	100R	100R	100R	19R	84R	MG	MG	MG	MG	G	G	MG	MG
	0.79	543	100R	100R	99R	100R	100R	100R	98R	98R	51R	54R	MG	G	G	G	G	G	G	G
	0.78	441	100R	100R	100R	100R	100R	100R	100R	100R	13R	36R	MG	MG	G	G	G	G	G	G
	0.70	542	100R	100R	100R	100R	100R	100R	100R	100R	100R	100R	G	GY	MG	MG	G	G	G	G
	0.74	443	100R	100R	100R	100R	100R	100R	100R	100R	41R	56R	MG	MG	MG	MG	G	G	MG	MG
	0.74	495	100R	100R	99R	100R	100R	100R	100R	100R	1R	2R	MG	MG	--	--	Cr	Cr	--	--
	0.76	541	100R	100R	100R	100R	100R	100R	100R	100R	1R	3R	G	GY	GY	GY	7R	7R	G	G
	0.76	440	100R	100R	100R	100R	100R	100R	100R	100R	44R	82R	GY	GY	GY	GY	GY	1R	G	G
	0.87	444	100R	100R	100R	100R	100R	100R	100R	100R	1R	1R	GY	GY	GY	GY	GY	1R	G	G
0.80 to 1.00 Avg. 0.88	1.05	348	100R	100R	G	G	27R	81R	G	2R	G	G	MG	MG	MG	MG	G	G	MG	MG
	0.81	248	100R	100R	100R	100R	100R	100R	100R	100R	16R	64R	MG	MG	MG	MG	G	G	MG	MG
	0.88	347	100R	100R	99R	100R	100R	100R	100R	100R	G	6R	MG	MG	MG	MG	G	G	MG	MG
	0.95	246	100R	100R	56R	66R	90R	93R	75R	89R	2R	11R	MG	MG	G	G	G	G	G	MG
	0.88	346	100R	100R	100R	100R	100R	100R	100R	100R	1R	1R	MG	MG	G	G	G	G	G	G
	0.81	245	100R	100R	99R	100R	99R	99R	100R	100R	G	5R	G	GY	G	GY	GY	GY	G	G
	0.81	296	100R	100R	59R	99R	100R	100R	100R	100R	G	G	G	G	--	--	--	--	--	--
	0.90	148	100R	100R	92R	99R	100R	100R	100R	100R	2R	2R	G	G	G	G	GY	GY	G	G
	0.85	149	100R	100R	87R	95R	100R	100R	96R	99R	29R	46R	MG	MG	MG	MG	G	G	MG	MG
	0.84	345	100R	100R	100R	100R	100R	100R	100R	100R	G	1R	GY	GY	GY	GY	GY	3R	GY	GY
	0.96	247	100R	100R	98R	99R	100R	100R	96R	100R	G	1R	GY	GY	GY	GY	GY	1R	G	GY
Avg. 1.28	1.35	800	100R	100R	Y	Y	19R	8R	Y	Y	5R	6R	MG	MG	--	--	G	G	--	--
	1.20	801	100R	100R	Y	3R	87R	97R	74R	62R	1R	1R	MG	MG	--	--	G	G	--	--
1.60 to 1.80 Avg. 1.76	2.08	552	100R	100R	G	G	G	G	G	G	G	G	MG	MG	MG	MG	G	G	MG	MG
	1.83	451	100R	100R	G	G	G	G	G	G	G	G	MG	MG	MG	MG	G	G	MG	MG
	1.75	350	100R	100R	G	G	G	G	G	G	G	G	MG	MG	MG	MG	G	G	MG	MG
	1.69	252	100R	100R	G	G	G	G	G	G	G	G	MG	MG	MG	MG	G	G	MG	MG
	1.65	351	100R	100R	G	1R	3R	1R	1R	1R	G	G	MG	MG	G	G	G	G	MG	MG
	1.76	250	99R	100R	G	G	G	GY	G	G	G	G	MG	MG	G	G	G	G	MG	MG
	1.69	551	100R	100R	G	G	G	G	G	G	G	G	MG	MG	MG	MG	G	G	MG	MG
	1.50	450	100R	100R	G	G	1R	1R	GY	TrR	G	G	MG	MG	MG	MG	G	G	MG	MG
	1.75	352	90R	100R	G	G	GY	GY	G	G	G	G	MG	MG	MG	MG	G	G	MG	MG
	1.86	251	86R	88R	G	G	GY	1R	1R	1R	G	1R	MG	MG	MG	MG	G	G	MG	MG
	1.86	151	62R	88R	1R	2R	10R	13R	12R	21R	G	G	MG	MG	MG	MG	G	G	MG	MG
Heavy Avg. 2.89	2.80	397	G	G	G	G	G	G	G	G	G	G	MG	MG	MG	MG	G	G	MG	MG
	2.72	298	G	G	G	G	G	G	G	G	G	G	MG	MG	MG	MG	G	G	MG	MG
	3.00	299	G	G	G	G	G	G	G	G	G	G	MG	MG	--	--	G	G	--	--

a The zinc coating weight reported in this column is the average of all stripping test determinations made on samples of unfabricated wire, fence or barbed wire of the specific wire lot number.

(Continued on p. 130.)

TABLE I.—*Continued.*

	Gage	Wire No.	Bridgeport, Conn.		State College, Pa.		Lafayette, Ind.		Ithaca, N. Y.		Ames, Iowa		Manhattan, Kans.		Santa Cruz, Calif.		College Station Texas		Davis, Calif.	
			16.5 yr	17.5 yr	16.3 yr	17.3 yr	17.0 yr	18.0 yr	16.9 yr	17.9 yr	16.8 yr	17.8 yr	16.9 yr	17.9 yr	16.8 yr	17.8 yr	16.8 yr	17.8 yr	16.8 yr	17.8 yr
Copper covered wires	11	021, 7.42 oz.	Gn	Gn	Gn	Gn	Gn	Gn	Gn	Gn	Br	Br	Br	Br	Br	Br	Br	Br	Br	Br
	9	022, 9.24 oz.	Gn	Gn	Gn	Gn	Gn	Gn	Gn	Gn	Br	Br	Br	Br	Br	Br	Br	Br	Br	Br
Lead coated wires	6	040, 1.40 oz.	Gy	Y	100PHR+Y	100PHR+Y	37PHR	21PHR	22R+Y	18R+Y	9R	31PHY	7R	4R	18SR	16SR	17R+Y	4R+Y	19SR	19SR
	9	041, 1.48 oz.	GY	Y	100PHR+Y	100PHR+Y	35PHR	5PHR	20R+Y	20R+Y	50R	56R	18R	18R	61SR	61SR	56R+Y	11R+Y	61SR	61SR
	11	042, 1.68 oz.	Y	Y	100PHR+Y	100PHR+Y	59PHR	10PHR	15R+Y	18R+Y	42R	46R	7R	8R	23SR	23SR	24R+Y	6R+Y	26SR	26SR
	14-1/2	043, 1.90 oz.	Y	Y	100PHR+Y	100PHR+Y	33PHR	5PHR	12R+Y	8R+Y	70R	70R	G	G	40SR	41SR	M	Y	18SR	18SR
Corrosion Resistant Uncoated Wires																				
12-14% Cr, cold drawn	12	001	Y	Y	M	G	M	R*	Y*	Y*	SY	SY	M	M	96SR	9R	3R+Y	3R+Y	49SR	6R
	9	004	GY	Y	M	G	M	R*	Y*	Y*	SY	SY	M	M	76SR	6R	1R+Y	1R+Y	44SR	7R
	17	005	Y	Y	M	MG	M	R*	Y*	Y*	SY	SY	M	M	98SR	10R	27R+Y	13R+Y	57SR	7R
12-14%, Cr, air quenched	13	002	GY	GY	M	MG	M	G	Y*	Y*	SY	SY	M	M	28SR	27SR	6R+Y	1R+Y	20SR	20SR
	10	006	GY	Y	M	G	M	G	Y*	Y*	SY	SY	M	M	26SR	26SR	56R+Y	GY	16SR	16SR
	18	007	GY	Y	M	MG	M	R*	Y*	Y*	SY	SY	M	M	65SR	1R	4R+Y	4R+Y	41SR	41SR
18% Cr-8% Ni	15	003	MG	MG	M	M	M	M	M	M	SY	SY	M	M	MG	MG	MGTrY	GY	MG	MG
	12	008	MG	MG	M	M	M	M	M	M	SY	SY	M	M	MG	MG	MGTrY	GY	MG	MG
	20	009	MG	MG	M	M	M	M	M	M	SY	SY	M	M	MG	MG	MGTrY	GY	MG	MG
	14	015	MG	MG	M	M	M	MG	M	M	SY	SY	M	M	MG	—	MGTrY	GY	MG	--

TABLE II.—REPORT OF 1953 AND 1954 INSPECTIONS OF BARBED WIRE SPECIMENS.

Abbreviations of symbols used to designate appearance or state of corrosion: M = metallic; G = gray; Y = yellowed, or rust-stained, but not showing actual rough rust of base metal; R = rough rust of base metal; PHR, PHY = rusted or yellowed in pinholes; asterisk (*) = speckled appearance of rust or yellowing; SR, SY = superficial R or Y; Br, Gn, respectively, signify corroded to a brown or green appearance; MG = intermediate between M and G; GY = predominantly gray but showing indication of Y; RB = rust on barbs; R+Y = indistinguishable proportions of R and Y. Figures preceding R (as 5, 20, 50, 100) are percentages.

Coating Group	Average Coating, oz per sq ft of surface[a]	Wire[b]	State College, Pa.		Lafayette, Ind.		Ames, Iowa		Manhattan Kans.		Ithaca, N. Y.		Santa Cruz, Calif.		College Station, Tex.		Davis, Calif.	
			15.4 yr	16.4 yr	17.0 yr	18.0 yr	16.8 yr	17.8 yr	17.0 yr	18.0 yr	16.9 yr	17.9 yr	16.8 yr	17.8 yr	16.8 yr	17.8 yr	16.8 yr	17.8 yr
0.20 to 0.30	0.30	No. C410	100R	100R	100R	100R	100R	100R	100R	100R	100R	100R	90R	100R	100R	100R	60R	50R
	0.24	No. C411	100R	100R	100R	100R	100R	100R	30R	60R	100R	100R	90R	100R	100R	100R	75R	95R
	0.29	No. C412	100R	100R	100R	100R	100R	100R	20R	20R	100R	100R	30R	28R	40R	40R	GY	GY
0.35 to 0.45	0.37	No. C421	100R	100R	100R	100R	100R	100R	GY	GY	100R	100R	20R	18R	10R	5R	GY	GY
	0.47	No. C422	100R	100R	100R	100R	100R	100R	20R	20R	100R	100R	20R	23R	25R	30R	GY	GY
	0.31	No. C420	100R	100R	100R	100R	100R	100R	25R	60R	100R	100R	25R	28R	30R	30R	GY	3R
0.50 to 0.60	0.48	No. C430	100R	100R	100R	100R	95R	100R	G	G	100R	100R	20R	18R	Y	Y	GY	GY
	0.54	No. C431	100R	100R	100R	100R	10R	15R	GRB	GRB	75R	60R	25R	23R	50R	40R	GY	GY
	0.57	No. C432	100R	100R	100R	100R	20R	50R	MG	MG	100R	100R	G	G	G	G	MG	MG
0.70 to 0.85	0.72	No. C441	30R	73R	100R	100R	GRB	GRB	MG	MG	100R	100R	G	G	G	G	MG	MG
	0.78	No. C442	20R	98R	100R	100R	GRB	GRB	MG	MG	60R	80R	G	G	G	G	MG	MG
	0.74	No. C443	100R	100R	100R	100R	30R	30R	G	MG	100R	100R	G	G	G	G	MG	G
0.80 to 1.00	0.97	No. C445	GY	GY	40R	20R	G	G	MG	MG	GY	GY	G	G	G	G	MG	MG
	0.92	No. C446	GRB	GYRB	30R	25R	GRB	GRB	MG	MG	10R	8R	G	G	G	G	MG	MG
1.60 to 1.80	1.64	No. C450	GY	5RRB	25R	50R	G	G	MG	MG	20R	25R	G	G	G	G	MG	MG
	1.50	No. C452	GY	G	5R	2R	G	G	MG	MG	GY	G	G	G	G	G	MG	MG
	1.83	No. C451	GRB	GRB	10R	GY	GRB	GRB	MG	MG	40R	45R	G	G	G	G	MG	MG
Heavy Coating	1.99	No. C494	G	G	G	G	G	G	MG	MG	Y	GY	G	G	G	G	MG	MG
	1.99	No. C494	G	G	G	G	G	G	MG	MG	MG	G	G	G	G	G	MG	MG
	2.00	No. C447	GRB	GRB	10R	GY	GRB	GRB	MG	MG	50R	28R	G	G	G	G	MG	MG

(Continued on p. 132.)

TABLE II.—*Concluded.*

Coating Group	Wire[b]	State College, Pa.		Lafayette, Ind.		Ames, Iowa		Manhattan Kans.		Ithaca, N. Y.		Santa Cruz, Calif.		College Station, Tex.		Davis, Calif.	
		15.4 yr	16.4 yr	17.0 yr	18.0 yr	16.8 yr	17.8 yr	17.0 yr	18.0 yr	16.9 yr	17.9 yr	16.8 yr	17.8 yr	16.8 yr	17.8 yr	16.8 yr	17.8 yr
Copper covered (3.97 oz per sq ft)	No. C025	Gn	Gn	Gn	Gn	Br	Br	Br	Br	Gn	GnRB	GnRB	GnRB	Br	Br	GnRB	GnRB
	No. C025	Gn	Gn	...	...	...	...	...	...	...	...	...	...	...	...	...	...
Lead-coated (1.83 oz per sq ft)	No. C045	...	...	40PHR	5PHR	30R	30R	10PHY	10PHY	40R	30R	...	...	4R	4R	...	...
	No. C045	...	...	40PHR	5PHR	20R	20R	...	...	30R	20R	35SR	33SR	4R	4R	25SR	25SR

[a] The zinc coating weight reported in this column is the average of all stripping test determinations made on samples of unfabricated wire, fence or barbed wire of the specific wire lot number.

[b] These barbed wire numbers do not always correspond to the unfabricated wire numbers as seen opposite:

Barbed Wire	Unfabricated Wire	Barbed Wire	Unfabricated Wire
No. C410	No. 410	No. C441	No. 442
No. C411	...	No. C442	No. 441
No. C412	No. 412	No. C443	No. 443
No. C421	...	No. C445	...
No. C422	No. 421	No. C446	...
No. C420	No. 423	No. C447	...
No. C430	No. 431	No. C450	...
No. C432	No. 432	No. C451	No, 451
No. C431	No. 430	No. C494	...

TABLE III.—REPORT OF 1953 AND 1954 INSPECTIONS OF FARM FIELD FENCE SPECIMENS.

Abbreviations and symbols used to designate appearance or state of corrosion: M = metallic; G = gray; Y = yellowed, or rust-stained, but not showing actual rough rust of base metal; R = rough rust of base metal; PHR, PHY = rusted or yellowed in pinholes; asterisk (*) = speckled appearance of rust or yellowing; SR, SY = superficial R or Y; Br, Gn, respectively, signify corroded to a brown or green appearance; MG = intermediate between M and G; GY = predominantly gray but showing indication of Y. Tr signifies trace of rust. Figures preceding R (as 5, 20, 50, 100) are percentages.

Coating Group	Average Coating, oz per sq ft of surface[a]	Fence	State College, Pa.[b]		Lafayette, Ind.		Ames, Iowa		Manhattan, Kans.		Ithaca, N. Y.		Santa Cruz, Calif.		College Station, Tex.		Davis, Calif.	
			15.4 yr	16.4 yr	17.0 yr	18.0 yr	16.8 yr	17.8 yr	16.9 yr	17.9 yr	16.9 yr	17.9 yr	16.8 yr	17.8 yr	16.8 yr	17.8 yr	16.9 yr	17.9 yr
0.20	0.27	No. 512	100R	100R	100R	100R	100R	100R	100R	100R	100R	100R	85R	83R	100R	100R	90R	90R
to	0.30	No. 410	100R	100R	100R	100R	100R	100R	100R	100R	100R	100R	60R	66R	100R	100R	90R	90R
0.30	0.28	No. 411	100R	100R	100R	100R	100R	100R	30R	40R	100R	100R	70R	100R	100R	100R	60R	60R
Avg.	0.29	No. 510	100R	100R	100R	100R	100R	100R	100R	50R	100R	100R	90R	95R	100R	100R	60R	60R
0.28	0.29	No. 412	100R	100R	100R	100R	100R	100R	20R	50R	100R	100R	95R	100R	100R	100R	60R	50R
	0.24	No. 511	100R	100R	100R	100R	100R	100R	50R	25R	100R	100R	95R	95R	100R	100R	100R	100R
0.25	0.25	No. 315	100R	100R	100R	100R	100R	100R	60R	50R	100R	100R	95R	95R	100R	100R	100R	100R
to	0.28	No. 215	100R	100R	100R	100R	100R	100R	70R	50R	100R	100R	85R	90R	100R	100R	100R	100R
0.35	0.38	No. 317	100R	100R	100R	100R	100R	100R	5R	5R	100R	100R	30R	35R	20R	30R	10R	5R
Avg.	0.32	No. 316	100R	100R	100R	100R	100R	100R	15R	25R	100R	100R	60R	80R	90R	100R	40R	30R
0.30	0.30	No. 216	100R	100R	100R	100R	100R	100R	15R	20R	100R	100R	35R	43R	60R	90R	20R	15R
0.35	0.36	No. 520	100R	100R	100R	100R	100R	100R	10R	10R	100R	100R	20R	23R	100R	100R	GY	13R
to	0.35	No. 422	100R	100R	100R	100R	100R	100R	20R	50R	100R	100R	50R	68R	60R	80R	20R	18R
0.45	0.31	No. 423	100R	100R	100R	100R	100R	100R	10R	10R	100R	100R	25R	35R	80R	85R	GY	GY
Avg.	0.44	No. 522	100R	100R	100R	100R	100R	100R	G	G	100R	100R	15R	23R	25R	38R	GY	GY
0.38	0.38	No. 521	100R	100R	100R	100R	100R	100R	20R	25R	100R	100R	55R	58R	55R	80R	40R	30R
	0.47	No. 421	100R	100R	100R	100R	100R	100R	10R	10R	100R	100R	20R	25R	30R	50R	20R	18R
0.45	0.44	No. 325	100R	100R	100R	100R	100R	100R	GY	GY	100R	100R	25R	23R	10R	10R	GY	GY
to	0.50	No. 228	100R	100R	100R	100R	100R	100R	GY	GY	100R	100R	35R	30R	15R	15R	GY	GY
0.55	0.51	No. 227	100R	100R	100R	100R	100R	100R	GY	GY	100R	100R	35R	30R	15R	15R	GY	GY
Avg.	0.38	No. 326	100R	100R	100R	100R	100R	100R	5R	10R	100R	100R	35R	40R	25R	38R	GY	GY
0.46	0.47	No. 327	100R	100R	100R	100R	100R	100R	G	G	100R	100R	15R	15R	GY	GY	GY	GY
	0.45	No. 225	100R	100R	100R	100R	100R	100R	G	GY	100R	100R	15R	18R	GY	GY	GY	GY

(Continued on pp. 134–135.)

TABLE III.—*Continued.*

Coating Group	Average Coating, oz per sq ft of surface[a]	Fence	State College, Pa.[b]		Lafayette, Ind.		Ames, Iowa		Manhattan, Kans.		Ithaca, N. Y.		Santa Cruz, Calif.		College Station, Tex.		Davis, Calif.	
			15.4 yr	16.4 yr	17.0 yr	18.0 yr	16.8 yr	17.8 yr	16.9 yr	17.9 yr	16.9 yr	17.9 yr	16.8 yr	17.8 yr	16.8 yr	17.8 yr	16.9 yr	17.9 yr
0.50 to 0.60 Avg. 0.54	0.61	No. 530	100R	100R	100R	100R	50R	50R	MG	MG	100R	100R	MG	MG	G	G	MG	MG
	0.57	No. 432	60R	78R	100R	100R	. . .	40R	MG	MG	100R	100R	MG	MG	G	G	MG	MG
	0.60	No. 531	100R	100R	100R	100R	100R	100R	MG	G	100R	100R	MG	G	G*	2R	G	GY
	0.48	No. 431	100R	100R	100R	100R	10R	90R	G	G	100R	100R	10R	10R	5R	4R	GY	GY
	0.54	No. 430	100R	100R	100R	100R	70R	95R	GY	GY	100R	100R	15R	15R	GY	3R	GY	GY
	0.49	No. 532	100R	100R	100R	100R	100R	100R	GY	GY	100R	100R	20R	20R	5R	8R	G	G
	0.49	No. 433	100R	100R	100R	100R	100R	100R	GY	GY	100R	100R	15R	13R	10R	10R	GY	GY
0.60 to 0.70 Avg. 0.64	0.69	No. 338	10R	18R	80R	85R	G	40R	MG	MG	70R	65R	MG	MG	G	G	MG	MG
	0.68	No. 236	1R	10R	100R	100R	G	G	MG	MG	60R	78R	MG	MG	G	G	MG	MG
	0.61	No. 335	100R	100R	100R	100R	75R	75R	MG	G	100R	100R	G	GY	GY	GY	MG	G
	0.63	No. 237	95R	98R	90R	95R	80R	80R	MG	G	98R	99R	MG	GY	GY	GY	MG	MG
	0.57	No. 337	100R	100R	100R	100R	20R	70R	GY	GY	100R	100R	20R	18R	10R	8R	GY	GY
	0.67	No. 235	100R	100R	100R	100R	95R	95R	GY	GY	100R	100R	20R	18R	10R	8R	GY	GY
	0.66	No. 336	100R	100R	100R	100R	10R	20R	GY	GY	100R	100R	25R	23R	Y	5R	GY	GY
	0.60	No. 238	100R	100R	100R	100R	50R	60R	GY	GY	100R	100R	25R	25R	5R	3R	GY	GY
0.70 to 0.85 Avg. 0.74	0.70	No. 540	35R	85R	90R	90R	G	G	MG	MG	90R	85R	MG	MG	G	G	MG	MG
	0.72	No. 442	GY	5R	60R	75R	G	G	MG	MG	15R	65R	MG	MG	G	G	MG	MG
	0.79	No. 543	93R	98R	100R	100R	30R	30R	MG	MG	98R	95R	G	G	G	GY	MG	MG
	0.78	No. 441	65R	95R	100R	100R	5R	10R	MG	MG	95R	95R	G	G	G	G	MG	MG
	0.70	No. 542	100R	100R	100R	100R	25R	25R	G	G	95R	95R	G	G	GY	GY	G	G
	0.74	No. 443	90R	100R	100R	100R	5R	20R	MG	MG	100R	100R	MG	MG	GY	GY	MG	MG
	0.76	No. 541	80R	88R	100R	100R	25R	25R	MG	MG	90R	100R	G	G	G	G	MG	MG
	0.76	No. 440	60R	80R	100R	100R	50R	50R	MG	MG	90R	95R	G	G	G	G	MG	MG
0.80 to 1.00 Avg. 0.90	1.05	No. 348	G	G	10R	15R	G	G	MG	MG	G	TrR	MG	MG	G	G	MG	MG
	0.81	No. 248	G	G	15R	30R	G	G	MG	MG	1R	2R	MG	MG	G	G	MG	MG
	0.88	No. 347	5R	15R	90R	99R	5R	5R	MG	MG	50R	65R	5R	10R	G	G	MG	MG
	0.95	No. 246	2R	8R	90R	100R	15R	15R	MG	MG	70R	78R	G	G	G	G	MG	MG
	0.88	No. 346	40R	80R	100R	100R	5R	5R	MG	MG	80R	55R	G	G	G	GY	MG	MG
	0.81	No. 245	80R	95R	100R	100R	G	G	MG	G	95R	93R	G	G	GY	GY	MG	MG
	0.84	No. 345	85R	98R	100R	100R	G	G	GY	GY	100R	100R	7R	6R	GY	3R	G	GY
	0.96	No. 247	50R	65R	90R	100R	G	G	GY	GY	80R	80R	10R	8R	5R	5R	GY	GY

1.60	1.75	No. 350	G	G	G	G	G	G	MG	MG	G	G	MG	MG	G	G	MG	MG
to	1.69	No. 252	G	G	G	G	G	G	MG	MG	MG	G	MG	MG	G	G	MG	MG
1.80	1.75	No. 352	GY	2R	5R	2R	G	G	MG	MG	GY	TrR	G	G	G	G	MG	MG
Avg.	2.80	No. 397	G	G	G	G	G	G	MG	MG	MG	G	MG	MG	G	G	MG	MG
2.76	2.72	No. 298	G	G	G	G	G	G	MG	MG	MG	G	MG	MG	G	G	MG	MG
12–14% Cr, cold drawn		No. 001	MG	G	M	MG	Y*	Y*	M*	MG	MG*	Y*	90R*	10R	20R	3R	80R	80R*
12–14% Cr, air quenched		No. 002	MG	MG	M	MG	Y*	Y*	MG	M	MG*	Y*	40R*	5R	8R	2R	40SR	40R*
18% Cr, 8% Ni		No. 003	M	M	M	M	M	M	M	M	M	M	MG	MG	MG	MG	MG	MG
Copper covered (7.42 oz per sq ft)		No. 020	Gn	Gn	Gn	Gn	Br	Br	Br	Br	Gn	Gn	Gn	Gn	Br	Br	Br	Br
Lead coated (1.48 oz per sq ft)		No. 040	100R+	Y100R+Y	35PHR	5PHR	30R	30R	15R	10R	40R	20R	45SR	49SR	20R	15R	40R	40SR

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[a] The zinc coating weight reported in this column is the average of all stripping test determinations made on samples of unfabricated wire, fence or barbed wire of the specific wire lot number.

[b] The rating for the state of corrosion is based on the appearance of the top half of the fence. At all locations the bottom part of the fence shows less corrosion than the top part.

TABLE IV.—REPORT OF 1953 AND 1954 INSPECTIONS OF CHAIN LINK FENCE SPECIMENS.

Abbreviations and symbols used to designate appearance or state of corrosion: M = metallic; G = gray; Y = yellowed, or rust-stained, but not showing actual rough rust of base metal; R = rough rust of base metal; PHR, PHY = rusted or yellowed in pinholes; Br, Gn, respectively, signify corroded to a brown or green appearance; SR, SY = superficial R or Y; MG = intermediate between M and G; GY = predominantly gray but showing indication of Y; R+Y = indistinguishable proportions of R and Y. Figures preceding R (as 5, 20, 50, 100) are percentages.

All 200 series wires are 9 gage. Lead-coated wire, 9 gage. Corrosion-resistant steel wire, 14 gage.

All 100 series wires are 6 gage. Copper-covered wire, 0.128 in. diameter.

Zinc Coating, oz per sq ft of surface, by Stripping Test	Fence	Bridgeport, Conn.[c]		State College, Pa.		Lafayette, Ind.		Ithaca, N. Y.		Santa Cruz, Calif.		Davis, Calif.	
		16.5 yr	17.5 yr	15.4 yr	16.4 yr	17.0 yr	18.0 yr	16.9 yr	17.9 yr	16.8 yr	17.8 yr	16.9 yr	17.9 yr
0.29	No. E280[a]	100R*		100R	100R	100R	100R	100R	100R	75R	90R	60R	60R
0.52	No. E281	100R*		100R	100R	100R	100R	100R	100R	10R	10R	5R	5R
0.37	No. E282	100R*		100R	100R	100R	100R	100R	100R	15R	18R	10R	6R
1.22	No. E185	100R*		Y	Y	20R	35R	Y	Y	MG	MG	MG	MG
1.13	No. E285	100R*		40R	50R	100R	100R	20R	78R	MG	MG	MG	MG
2.92	No. E290	G	G	G	G	G	G	G	G	MG	MG	MG	MG
2.09	No. E291	GY	GY	G	2R	G	G	G	G	MG	MG	MG	MG
1.60	No. H280[a]	100R*		5R	20R	80R	50R	40R	55R	G	G	MG	MG
1.83	No. H185	100R*		GY	GY	40R	25R	10R	18R	MG	MG	MG	MG
1.60	No. H186	100R*		GY	GY	20R	15R	Y	Y	G	G	MG	MG
1.61	No. H187	100R*		GY	GY	10R	GY	Y	Y	G	G	MG	MG
1.55	No. H188	100R*		GY	2R	60R	45R	20R	28R	MG	MG	G	MG
1.36	No. H285	100R*		GY	GY	30R	25R	5R	28R	G	G	MG	MG
1.97	No. H286	100R*		GY	GY	25R	15R	Y	13R	MG	MG	MG	MG
1.46	No. H287	100R*		GY	2R	40R	25R	45R	30R	MG	MG	MG	MG
1.74	No. H288	100R*		Y	Y	10R	Y	Y	Y	G	G	MG	MG
1.40	No. H289[b]	100R*		G	G	G	G	G	G	MG	MG	MG	MG
4.21	No. H290	GY	Y	GY	GY	G	GY	GY	Y	MG	MG	MG	MG

Lead-coated (1.75 oz per sq ft)	No. L050	Y	Y	100PHR +Y	100PHR +Y	40PHR	20PHR	40R	18R	35SR	35SR	35SR	35SR
Copper-covered (8.52 oz per sq ft)	No. K030	Gn	Gn	Gn	Gn	Gn	Gn	Gn	Gn	Br	Br	Br	Br
Corrosion-resistant steel (18% Cr-8% Ni)	No. J011	MG	MG	M	M	M	MG	M	M	MG	MG	MG	MG

[a] E numbers, coating applied before weaving; H numbers, coating applied after weaving.

[b] Although this sample has an H number, its appearance indicates that it was galvanized before weaving.

[c] The rating for the state of corrosion is based on the appearance of the fence at eye level. At all exposure sites the bottom part of the fence is less corroded than the upper part of the fence.

* Specimens destroyed shortly after this inspection.

TABLE V.—REPORT OF 1953 AND 1954 INSPECTIONS OF WIRE STRAND SPECIMENS.

Abbreviations and symbols used to designate appearance or state of corrosion: M = metallic; G = gray; Y = yellowed or rust-stained, but not showing actual rough rust of base metal; R = rough rust of base metal; PHR, PHY = rusted or yellowed in pinholes; Br, Gn, respectively, signify corroded to a brown or green appearance; SR, SY = superficial R or Y; MG = intermediate between M and G; GY = predominantly gray but showing indication of Y; R+Y = indistinguishable proportions of R and Y. Tr signifies trace of rust. Figures preceding R (as 5, 20, 50, 100) are percentages.

Zinc Coating, oz per sq ft of surface	Strand	Bridgeport, Conn.		State College, Pa.		Lafayette, Ind.		Ames, Iowa		Manhattan, Kans.	
		16.5 yr	17.5 yr	16.3 yr	17.3 yr	17.0 yr	18.0 yr	16.8 yr	17.8 yr	16.9 yr	17.9 yr
0.69	No. D345	100R	100R	G	GY	10R	5R	G	G	MG	MG
0.88	No. D346	100R	100R	GY	GY	10R	TrR	G	G	MG	MG
0.87	No. D347	100R	100R	GY	GY	40R	25R	G	G	GY	MG
0.93	No. D348	100R	100R	G	G	10R	10R	G	G	MG	MG
1.10	No. D360	20R	50R	G	G	GY	GY	G	G	MG	MG
1.17	No. D361	25R	25R	GY	GY	10R	GY	G	G	MG	MG
1.03	No. D362	100R	100R	GY	GY	30R	10R	G	G	MG	MG
1.51	No. D365	Y	Y	GY	GY	25R	GY	G	G	MG	MG
1.39	No. D366	GY	GY	G	G	G	G	G	G	MG	MG
1.32	No. D367	95R	95R	Y	Y	30R	Y	G	G	MG	MG
1.71	No. D371	G	G	G	G	G	G	G	G	MG	MG
2.47	No. D375	G	G	G	G	G	G	G	G	MG	MG
Lead-coated (1.96 oz per sq ft)	No. D045	10PHR	Y	100R+Y	100R+Y	50PHR	25PHR	60R	63R	25R	15R

Zinc Coating, oz per sq ft of surface	Strand	Ithaca, N. Y.		Santa Cruz, Calif.		College Station, Tex.		Davis, Calif.	
		16.9 yr	17.9 yr	16.8 yr	17.8 yr	16.8 yr	17.8 yr	16.9 yr	17.9 yr
0.69	No. D345	15R	12R	G	G	G	G	G	G
0.88	No. D346	GY	GY	MG	MG	G	G	MG	MG
0.87	No. D347	GY	1R	G	G	G	G	G	G
0.93	No. D348	2R	1R	MG	MG	G	G	G	MG
1.10	No. D360	MG	G	MG	MG	G	G	MG	MG
1.17	No. D361	GY	1R	G	G	G	G	G	G
1.03	No. D362	GY	GY	MG	MG	G	G	G	MG
1.51	No. D365	GY	GY	G	G	G	G	G	G
1.39	No. D366	G	G	MG	MG	G	G	G	MG
1.32	No. D367	3R	GY	MG	G	G	G	G	MG
1.71	No. D371	G	G	MG	MG	G	G	MG	MG
2.47	No. D375	G	G	MG	G	G	G	G	MG
Lead-coated (1.96 oz per sq ft)	No. D045	70R	15R	68SR	68SR	10PHR	10PHR	10R	10R

TABLE VI.—LOSS OF TENSILE STRENGTH SHOWN BY STEEL WIRES AFTER VARIOUS PERIODS OF EXPOSURE.[b]
Bridgeport, Conn. 500 Series (14½ gage); 400 Series (12½ gage); 300 Series (11 gage); 200 Series (9 gage); and 100 Series (6 gage) Unfabricated Wires.

Wire Lot No.	Original Breaking Load, lb	Exposure Until First Rust, yr	First Test			Second Test			Third Test			Fourth Test			Fifth Test			Sixth Test			Seventh Test		
			Exp. Since 1R, yr	Tensile Strength Loss, %	Tensile Strength Loss, %/yr	Exp. Since 1R, yr	Tensile Strength Loss, %	Tensile Strength Loss, %/yr	Exp. Since 1R, yr	Tensile Strength Loss, %	Tensile Strength Loss, %/yr	Exp. Since 1R, yr	Tensile Strength Loss, %	Tensile Strength Loss, %/yr	Exp. Since 1R, yr	Tensile Strength Loss, %	Tensile Strength Loss, %/yr	Exp. Since 1R, yr	Tensile Strength Loss, %	Tensile Strength Loss, %/yr	Exp. Since 1R, yr	Tensile Strength Loss, %	Tensile Strength Loss, %/yr
*501[a]	500	0	1.45	16.0	11	1.91	23.0	12	2.42	21.0	9	2.91	24.0	8	5.45	33.0	6	8.45	44.0	5	10.35	46.0	4
*506	520	0	1.45	21.2	15	1.91	17.4	9	2.42	22.1	9	3.45	25.0	7	5.45	33.6	6	8.45	45.2	5	10.35	46.0	4
*507	590	0	1.45	17.6	12	1.91	17.6	9	2.42	20.2	8	3.45	26.9	8	5.45	36.1	6	8.45	48.6	6	10.35	48.0	5
510	500	2.50	0	-2.0	0	0.06	-6.0	0	1.60	5.0	3	3.44	16.0	5	5.95	28.0	5	7.85	36.0	5	10.00	41.0	4
511	280	1.80	0	8.8	0	0.11	-0.4	0	1.65	5.3	3	4.14	19.3	5	6.65	35.1	5	8.55	40.4	5	10.70	43.8	4
512	320	1.65	0	7.6	0	0.26	1.7	0	1.80	13.8	8	4.29	20.0	5	6.85	35.4	5	8.75	38.4	4	10.90	44.7	4
520	280	2.50	1.95	0	0	3.95	12.5	3	5.95	21.4	4	6.90	16.1	2	7.85	23.2	3	10.00	25.0	3			
521	270	3.45	1.00	-3.0	0	3.00	3.7	1	5.05	25.9	5	6.00	22.2	4	6.95	27.8	4	9.10	33.3	4			
522	500	3.45	1.00	1.0	1	3.00	14.0	5	5.05	32.0	6	6.00	34.0	6	6.95	32.0	5	9.10	36.0	4			
530	310	5.40	1.05	12.9	12	2.50	19.3	8	3.05	25.2	8	4.00	27.5	7	6.00	30.3	5	7.00	41.0	6	11.00	43.5	4
531	500	4.70	1.75	12.0	7	3.20	23.0	7	3.75	25.0	7	4.70	34.0	7	6.70	35.2	5	7.70	38.0	5	11.70	45.0	4
540	300	6.20	2.25	16.7	7	3.20	18.4	6	5.20	28.7	6	6.20	25.0	4	10.25	38.3	4						
541	350	4.90	3.55	7.1	2	4.50	14.3	3	6.50	24.9	4	7.50	27.1	4	11.55	31.4	3						
542	510	5.50	2.95	23.6	8	3.90	30.4	8	5.90	36.3	6	7.00	33.3	5	10.95	49.0	4						
543	300	5.90	2.55	13.3	5	3.50	16.7	5	5.50	31.3	6	6.50	26.6	4	10.55	41.7	4						
551	540	13.00	3.45	33.3	10																		
552	310	14.00	2.45	28.0	11																		

* Uncoated wires. All other wires were zinc coated.
[a] Low copper content wire, 0.05 to 0.08 percent copper. All other wires have approximately 0.25 percent copper.
[b] Summarizes data through 1954.

*400[a]	470	0	1.45	16.5	12	1.91	10.5	6	3.91	13.5	4	5.45	19.8	4	9.42	28.1	3	12.5	27.1	2			
*401[a]	440	0	1.45	15.5	11	1.91	11.0	6	3.91	17.8	5	5.45	24.4	4	9.42	30.0	3	12.5	33.3	3			
*405	470	0	1.45	17.5	12	1.91	13.5	7	2.91	13.4	5	5.45	20.6	4	9.42	25.8	3	12.5	33.0	3			
*406	460	0	1.45	15.0	11	1.91	8.5	4	2.91	10.7	4	5.45	18.1	3	9.42	21.3	2	12.5	23.4	2			
410	470	1.80	0	3.5	0	0.11	-5.3	0	1.65	3.5	2	4.14	10.5	3	9.60	26.7	3	10.60	22.8	2			
411	630	1.90	0	2.5	0	0	-11.4	0	1.55	1.6	1	4.04	5.7	1	9.10	19.2	2	10.10	22.0	2			
412	840	2.50	0	0	0	0	0	0	1.00	7.2	7	3.44	--	--	8.90	24.3	3	10.00	22.9	2	13.95	30.0	2
421	470	2.70	1.75	3.2	2	3.75	9.6	3	5.75	11.7	2	7.65	20.2	3	9.80	20.2	2	11.75	29.8	2			
422	500	2.70	1.75	5.0	3	3.75	7.0	2	5.75	11.0	2	7.65	17.0	2	9.80	18.0	2	11.75	27.0	2			
423	400	2.50	1.95	2.5	1	3.95	8.7	2	5.95	12.5	2	7.85	18.8	2	10.00	17.5	2	11.95	18.7	2			
430	780	4.90	1.55	--	--	3.00	8.3	3	3.65	8.3	2	5.55	14.1	3	9.65	26.2	3						
431	880	3.50	2.95	10.2	3	4.40	18.7	4	4.95	14.8	3	6.85	22.2	3	10.95	33.6	3						
432	510	5.40	1.05	0	0	2.50	8.8	4	3.05	4.9	2	4.95	15.7	3	9.05	26.5	3						
440	590	4.80	3.65	11.0	3	4.60	20.3	5	6.60	15.8	2	9.65	22.9	2									
441	520	5.90	2.55	8.6	3	3.50	18.3	5	5.50	21.7	4	8.55	28.0	3									
442	470	6.30	2.15	12.8	6	3.10	20.2	6	5.10	21.9	4	8.15	24.6	3									
443	750	5.80	2.65	12.0	5	3.60	18.6	5	5.60	18.2	3	8.65	26.0	3									
444	570	5.60	2.85	2.6	1	3.80	4.4	1	5.80	19.3	3	8.85	16.6	2									
495	750	5.90	2.55	12.0	5	3.50	18.7	5	5.50	18.0	3	8.55	27.4	3									
450	820	10.00	6.45	20.7	3																		
451	510	13.00	3.45	15.1	4																		
*300[a]	730	0	1.45	11.0	8	2.40	8.8	4	3.90	10.8	3	5.95	10.8	2	14.45	25.0	2						
*302[a]	1110	0	1.45	17.3	12	2.40	18.2	7	3.90	20.5	5	5.95	19.1	3	14.45	32.2	2						
*305	1070	0	1.45	9.0	6	2.40	10.1	4	3.90	15.2	4	5.95	14.7	2	14.45	29.1	2						
*306	700	0	1.45	7.0	5	2.40	7.7	3	3.90	7.7	2	5.95	8.5	1	14.45	24.0	2						
315	890	1.70	--	0.0	--	2.75	5.5	2	4.75	9.5	2	8.65	16.1	2	12.75	22.3	2						
316	1110	2.50	--	-3.5	--	1.65	-1.5	--	3.95	1.0	-	7.85	7.7	1	11.65	16.4	1						
317	780	2.80	--	-3.1	--	1.65	0.6	--	3.65	10.7	3	7.55	16.3	2	11.65	25.1	2						
325	730	3.90	2.55	2.1	1	4.55	9.6	2	6.45	10.3	2	10.55	17.8	2									
326[a]	700	2.90	3.55	8.6	2	5.55	14.6	3	7.45	20.7	3	11.55	27.2	2									
327	1160	3.90	2.55	8.2	3	4.55	13.8	3	6.45	16.9	3	10.55	23.3	2									
329	720	3.80	2.65	4.2	2	4.65	8.3	2	6.55	14.6	2	10.65	20.2	2									
335	1040	5.40	3.05	12.5	4	4.00	13.5	3	6.00	15.3	3	11.05	66.4	6									
336	760	5.40	3.05	7.9	3	4.00	12.5	3	6.00	13.5	2	11.05	25.6	2									
337	860	5.40	3.05	10.5	3	4.00	16.2	4	6.00	15.8	3	11.05	27.3	2									
338	1020	6.70	1.75	7.3	4	2.70	12.7	5	4.70	14.8	3	9.75	31.9	3									
345	890	5.70	2.75	12.7	5	3.70	5.1	1	10.75	27.4	3												
346	1070	6.90	1.55	7.0	5	2.50	12.6	5	9.55	20.0	2												
347	860	6.90	1.55	8.7	6	2.50	8.1	3	9.55	18.6	2												
348	980	9.30	--	1.6	--	--	3.1	--	7.15	15.3	2												
350	640	15.50	1.00	8.0	8																		
351	970	10.40	6.00	13.4	2																		
352	1340	10.70	5.70	16.7	3																		
397	940	--	--	0.0	--																		
*200[a]	1010	0	1.45	12.0	8	2.40	13.4	6	4.90	14.8	3	5.95	12.9	2	14.45	25.4	2						
*202[a]	1640	0	1.45	11.5	8	2.40	10.7	4	4.90	15.2	3	5.95	8.8	2	14.45	19.8	1						
*205	1110	0	1.45	9.0	6	2.40	9.5	4	4.90	7.7	2	5.95	5.4	1	14.45	20.3	1						
*206	1480	0	1.45	10.0	7	2.40	9.5	4	4.90	12.8	3	5.95	9.5	2	14.45	22.0	2						

(Continued on p. 142.)

TABLE VI.—*Continued.*

Wire Lot No.	Original Breaking Load, lb	Exposure Until First Rust, yr	First Test			Second Test			Third Test			Fourth Test			Fifth Test			Sixth Test			Seventh Test		
			Exp. Since 1R, yr	Tensile Strength Loss		Exp. Since 1R, yr	Tensile Strength Loss		Exp. Since 1R, yr	Tensile Strength Loss		Exp. Since 1R, yr	Tensile Strength Loss		Exp. Since 1R, yr	Tensile Strength Loss		Exp. Since 1R, yr	Tensile Strength Loss		Exp. Since 1R, yr	Tensile Strength Loss	
				%	%/yr		%	%/yr		%	%/yr		%	%/yr		%	%/yr		%	%/yr		%	%/yr
215	1200	1.80	--	1.0	--	2.60	2.5	1	4.60	7.0	2	10.70	12.8	1									
216	1630	2.80	--	0.0	--	1.65	3.1	2	3.65	7.4	2	9.70	11.6	1									
217	1080	2.70	--	-6.0	--	1.75	-2.0	—	3.75	4.6	1	9.80	10.2	1									
282	1320	2.80	1.65	1.1	1	3.65	3.0	1	5.65	6.1	1	7.55	13.2	2	11.65	18.9	2						
225	1650	3.90	2.55	4.2	2	4.55	6.1	1	7.50	11.7	2	10.55	13.9	1									
226	1150	3.90	2.55	3.0	1	4.55	5.2	1	7.50	9.8	1	10.55	14.8	1									
227	1640	4.40	2.05	4.6	2	4.05	9.9	2	7.00	12.5	2	10.05	16.2	2									
228	1080	3.80	2.65	0.0	--	4.65	6.0	1	7.60	8.0	1	10.65	12.1	1									
235	1680	5.70	2.75	0.6	--	8.75	8.6	1															
236	1270	6.80	1.65	0.0	--	7.65	4.7	1															
237	1540	4.90	3.55	4.9	1	9.55	16.5	2															
238	1650	4.90	3.55	6.1	2	9.55	13.3	1															
239	1120	4.40	4.05	4.9	1	9.55	12.5	1															
245	1570	5.90	2.55	2.5	1	8.55	11.2	1															
246	1190	6.90	1.55	0.0	--	7.55	10.1	1															
247	1790	5.90	2.55	4.7	2	8.55	16.5	2															
248	1450	6.80	1.65	5.5	3	7.65	7.9	1															
296	1570	6.90	1.55	0.6	—	7.55	9.9	1															
250	1380																						
251	1940	9.90	6.55	7.2	1																		
252	1150	13.00	3.45	9.0	3																		
298	1520	--	—	2.0	--																		
299	1840	--	--	1.4	--																		
*101[a]	2330	0	1.45	8.0	6	2.90	8.0	3	4.90	8.2	2	10.35	15.3	1	14.45	16.6	1						
*105[a]	2750	0	1.45	8.2	6	2.90	8.3	3	4.90	8.9	2	10.35	13.4	1	14.45	15.9	1						
*102	2110	0	1.45	11.0	8	2.90	8.8	3	4.90	12.9	3	10.35	16.2	2	14.45	15.7	1						
*106	2430	0	1.45	4.0	3	2.90	2.9	1	4.90	9.6	2	10.35	10.8	1	14.45	10.6	1						
115	2690	1.70	--	1.3	--	2.70	1.5	1	4.70	4.8	1	10.80	8.5	1									
117	2230	2.70	—	3.5	--	1.75	2.5	1	3.75	5.2	1	9.80	7.5	1									
125	1840	3.70	2.75	2.5	1	5.70	4.6	1	10.75	10.6	1												
127[a]	2540	4.00	2.45	2.0	1	5.40	6.3	1	10.45	10.4	1												
135	2560	4.90	3.55	4.1	1	9.55	10.3	1															
138	1960	4.90	3.55	4.1	1	9.55	8.7	1															
139	1920	4.90	3.55	3.4	1	9.55	8.4	1															
148	2550	6.90	1.55	4.3	3	7.55	6.1	1															
149	1910	6.90	1.55	4.4	3	7.55	7.6	1															
1.51	3100	10.40	6.05	9.3	2																		
800	26.70	9.50	3.00	7.9	3	4.95	10.7	2	6.95	16.0	2												
801	1820	8.50	4.00	25.0	6	5.95	27.8	5	7.95	30.5	5												

REFERENCE INFORMATION

ON UNFABRICATED WIRE, BARBED WIRE AND FENCE IN THE WIRE INSPECTION REPORT.

The Wire Test Committee responsible for planning and arranging the exposure tests of specimens covered in this report recommends that the following statement be made in all reports relating to the samples of wire and wire products under exposure tests:

> "It is emphasized that the weight of coating ranges shown under each weight group have been arbitrarily chosen and purposely held to close limitations by the Committee and do not necessarily individually represent any manufacturers' commercial product. On the other hand, the entire range of coatings covered by all weight groups as a whole are designed to include a sufficient range of coating to furnish the useful corrosion resistance data desired."

SYSTEM OF NUMBERING SPECIMENS

Zinc coated and uncoated steel specimens (all have 3-digit numbers)..................(*c*)

When the first digit is.......	5	4	3	2	1
the respective gages are:	14.5	12.5	11	9	6

The second and third digits indicate weight of zinc coating as follows:

	oz. per sq.ft.		oz. per sq.ft.
00–04 (LC)*	uncoated	50–59 (CB)	1.6 to 1.8
05–09 (CB)*	uncoated	60–64 (CB)	1.0 to 1.2
10–14 (CB)	0.20 to 0.30	65–69 (CB)	1.3 to 1.5
15–19 (CB)	0.25 to 0.35	70–74 (CB)	1.6 to 1.8
20–24 (CB)	0.35 to 0.45	75–79 (CB)	2.4 to 2.6
25–29 (CB)	0.45 to 0.55	80–84 (CB)	less than 0.50
30–34 (CB)	0.50 to 0.60	85–89 (CB)	1.2 to 1.5
35–39 (CB)	0.60 to 0.70	90–94 (CB)	2.4 to 3.0
40–44 (CB)	0.70 to 0.85	97–99 (CB)	extra heavy
		95–96 (CB)	chromated after coating
45–49 (CB)	0.80 to 1.00 on farm fence and unfabricated wire. 0.85 to 1.00 on barbed wire. 0.80 to 0.95 on wire strand.		

Specimens of Special Materials:
000–015: uncoated corrosion-resistant steel.
020–030: copper-covered steel.
040–050: lead-coated steel.

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* LC = low copper content wire; CB = copper bearing wire

Reference Characters

(*a*) .....Wire lot numbers identify wire from a coil or coils of wire supposedly alike.

Wire Lots of Zinc-Coated or Bare Mild Steel	Usually Appear in the Test as shown by ✓				
	Unfab. + Wire	Int. of + Fence	T and B + of Fence	T and B of Fence	Barbed Wire
100 series	✓ (S)	....	....	....	....
200 series	✓ (S)	✓ (S)	✓ (S)	✓ (300)	....
300 series	✓ (S)	✓ (S)	....	✓ (500)	....
400 series	✓ (S)	✓ (S)	....	....	✓ (400)
(*s*) ..... 500 series	✓ (S)	✓ (S)	....	....	....

(S) The specimen numbers of the unfabricated wire or fence are the same as the wire lot numbers.

(300), (400), (500): Specimens of fence numbered in the series 300 have top and bottom wires of the 200 series wire lots; fences numbered in the 500 series have top and bottom wires of the 300 series wire lots. Specimens of barbed wire (numbered in the 400 series) have wire lots of the 400 series but not necessarily of the same identical wire lot numbers.

Par. A. The zinc-coated wire lots table below shows:

(1) All the individual numbered wire lots and the various utilizations of each wire lot in the test.

(2) The results of weight of coating tests on samples cut from each source (un fabricated wire, fence interiors, fence top and bottom wires, and barbed wires)

(*b*)...... (3) The average coating for each wire lot which is the average of all the figures in the third and following columns in each row.

These average coating figures are the ones entered in other tables of this report For example, wherever unfabricated wire sample No. 317 or farm fence sample No. 317 are listed, their indicated weights of coating are 0.38 oz. per sq.ft., and not 0.46 and 0.34, respectively.

These wire lot and coating reference data provide an indication of the uniformity of coating on any wire lot.

Par B. The makeup of fences table below shows:

(1) The lot number of the wire used in the top and bottom line wires of each fence. (The lot number of the wire used in the interior line and stay wires of any fence is the same as the fence number.)

(2) The type of fence, that is, the combination of gages used in its fabrication as explained below:

(*d*)...... Type of fence..........................	4	3	2	1
Gage of interior line and stay wires....	14.5	12.5	11	9
Gage of top and bottom line wires......	11	10	9	9

+ ......Abbreviations: Unfab., unfabricated wire; Int., interior line and stay wire; T and B, top and bottom line wires

ZINC-COATED WIRE LOTS: THEIR COATING WEIGHTS AND TEST SPECIMENS IN WHICH THEY ARE USED
(See Par. A and reference characters above for explanations) (Coating weights, oz. per sq.ft.)

(*b*) Coating Weight

(*b*)

MAKEUP OF FENCES
(See Par. B and reference characters above)

(See Par. A and reference characters above for explanations) (Coating weights, oz. per sq.ft.)

Wire Lot (a) (Fence)	(b) Average Coating	Coating Weight Tests on Samples Cut From Unfab. Wire(s)	Coating Weight Tests on Samples Cut From Fence Int.(s)	Barbed Wire Coating	Barbed Wire No.
No. 510(c)	0.29	0.29	0.29		
No. 511	0.24	0.24	0.23		
No. 512	0.27	0.27	0.27		
No. 520	0.36	0.34	0.38		
No. 521	0.38	0.40	0.36		
No. 522	0.44	0.44	0.44		
No. 530	0.61	0.59	0.62		
No. 531	0.60	0.58	0.61		
No. 532	0.49	....	0.49		
No. 540	0.70	0.72	0.68		
No. 541	0.76	0.80	0.72		
No. 542	0.70	0.69	0.71		
No. 543	0.79	0.83	0.74		
No. 551	1.69	1.69	....		
No. 552	2.08	2.08	....		
No. 410(c)	0.30	0.25	0.38	0.27	(410)
No. 411	0.28	0.28	0.28	....	....
No. 412	0.29	0.30	0.30	0.27	(412)
No. 421	0.47	0.49	0.49	0.44	(422)
No. 422	0.35	0.38	0.31	....	....
No. 423	0.31	0.35	0.31	0.28	(420)
No. 430	0.54	0.56	0.52	0.53	(431)
No. 431	0.48	0.49	0.48	0.46	(430)
No. 432	0.57	0.58	0.60	0.53	(432)
No. 433	0.49	....	0.49	....	....
No. 440	0.76	0.72	0.79	....	....
No. 441	0.78	0.77	0.76	0.82	(442)
No. 442	0.72	0.65	0.86	0.64	(441)
No. 443	0.74	0.74	0.78	0.70	(443)
No. 444	0.87	0.87	....	....	....
No. 450	1.50	1.48	....	1.52	(452)
No. 451	1.83	1.71	....	1.95	(451)
No. 495 Cr	Made from unfab. wire 443.				

	Unfab. Wire		Unfab. Wire
No. 115(c)	0.25	No. 139	0.64
No. 117	0.27	No. 148	0.90
No. 125	0.41	No. 149	0.85
No. 127	0.54	No. 151	1.86
No. 135	0.74	No. 800(6 ga.)	1.35
No. 138	0.67	No. 801(9 ga.)	1.20

Wire Lot (a) (Fence)	(b) Average Coating	Coating Weight Tests on Samples Cut From Untab. Wire(s)	Fence Int.(s)	T and B of Fence Top	T and B of Fence Bottom	T and B of Fence No.
No. 315(c)	0.25	0.25	0.25	0.25	0.26	(512)
No. 316	0.32	0.32	0.31	0.32	0.33	(510)
No. 317	0.38	0.46	0.34	0.37	0.36	(511)
No. 325	0.44	0.50	0.52	0.37	0.39	(520)
No. 326	0.38	0.40	0.35	....	....	....
No. 327	0.47	0.48	0.44	0.48	0.48	(522)
No. 329	0.54	0.56	....	0.45	0.61	(521)
No. 335	0.61	0.61	0.63	0.59	0.60	(531)
No. 336	0.66	0.73	0.60	....	....	....
No. 337	0.57	0.66	0.59	0.50	0.52	(532)
No. 338	0.69	0.67	0.76	0.67	0.65	(530)
No. 345	0.84	0.83	0.97	0.76	0.79	(541)
No. 346	0.88	0.84	0.84	0.96	0.88	(542)
No. 347	0.88	0.96	1.00	0.78	0.79	(543)
No. 348	1.05	1.04	1.07	1.05	1.06	(540)
No. 350	1.75	1.73	1.76	....	....	....
No. 351	1.65	1.65	....	....	....	....
No. 352	1.75	1.82	1.68	....	....	....
No. 397	2.80	2.80	2.79	....	....	....

			Fence(s) T-B Top	Fence(s) T-B Bottom	T and B of Fence Top	T and B of Fence Bottom	T and B of Fence No.
No. 215(c)	0.28	0.28	0.25	0.25	0.33	0.29	(315)
No. 216	0.28	0.31	0.30	0.31	0.27	0.29	(316)
No. 217	0.36	0.29	....	....	0.40	0.39	(317)
No. 225	0.45	0.45	0.49	0.44	0.43	0.47	(327)
No. 226	0.45	0.46	....	....	0.45	0.45	(326)
No. 227	0.51	0.59	0.48	0.49	....	....	
No. 228	0.50	0.49	0.48	0.48	0.50	0.53	(325)
No. 235	0.67	0.82	0.60	0.62	0.68	0.64	(337)
No. 236	0.68	0.66	0.68	0.73	0.69	0.65	(338)
No. 237	0.63	0.72	0.67	0.55	0.58	0.61	(335)
No. 238	0.60	0.60	0.59	0.61	0.59	0.61	(336)
No. 239	0.65	0.65	....	....	....	....	....
No. 245	0.81	0.80	0.83	0.78	0.81	0.81	(346)
No. 246	0.95	0.97	0.94	0.98	0.89	0.95	(347)
No. 247	0.96	0.94	0.95	1.00	1.01	0.91	(345)
No. 248	0.81	0.66	0.92	0.68	0.91	0.89	(348)
No. 250	1.76	1.76	....	....	....	....	....
No. 251	1.86	1.68	....	....	1.99	1.91	(352)
No. 252	1.69	1.67	1.85	1.57	....	....	(350)
No. 282	0.37	0.37	....	....	....	....	....
No. 296 Cr	Made from unfab. wire 245.						
No. 298	2.72	2.78	2.71	2.74	2.71	2.67	(397)
No. 299	3.00	3.00	....	....	....	....	....

(See Par. B and reference characters above)

Int. Lot (Fence)	Type (d)	T-B Lot	Int. Lot (Fence)	Type (d)	T-B Lot
ZINC-COATED FENCES					
No. 510	4	No. 316	No. 410	3	....
No. 511	4	No. 317	No. 411	3	....
No. 512	4	No. 315	No. 412	3	....
No. 520	4	No. 325	No. 421	3	....
No. 521	4	No. 329	No. 422	3	....
No. 522	4	No. 327	No. 423	3	....
No. 530	4	No. 338	No. 430	3	....
No. 531	4	No. 335	No. 431	3	....
No. 532	4	No. 337	No. 432	3	....
No 540	4	No. 348	No. 433	3	....
No. 541	4	No. 345	No. 440	3	....
No. 542	4	No. 346	No. 441	3	....
No. 543	4	No. 347	No. 442	3	....
			No. 443	3	....
No. 315	2	No. 215			
No. 316	2	No. 216	No. 215	1	No. 215
No. 317	2	No. 217	No. 216	1	No. 216
No. 325	2	No. 228	No. 225	1	No. 225
No. 326	2	No. 226	No. 227	1	No. 227
No. 327	2	No. 225	No. 228	1	No. 228
No. 335	2	No. 237	No. 235	1	No. 235
No. 336	2	No. 238	No. 236	1	No. 236
No. 337	2	No. 235	No. 237	1	No. 237
No. 338	2	No. 236	No. 238	1	No. 238
No. 345	2	No. 247	No. 245	1	No. 245
No. 346	2	No. 245	No. 246	1	No. 246
No. 347	2	No. 246	No. 247	1	No. 247
No. 348	2	No. 248	No. 248	1	No. 248
No. 350	2	No. 252	No. 252	1	No. 252
No. 352	2	No. 251	No. 298	1	No. 298
No. 397	2	No. 298			
BARE-STEEL FENCES					
No. 505	4	No. 306	No. 305	2	No. 206
No. 506	4	No. 305	No. 306	2	No. 207
No. 405	3	....	No. 205	1	No. 205
No. 406	3	....	No. 206	1	No. 206
Coppered-covered steel fence No. 020			Int. No. 021	2	No. 022
Lead-coated steel fence No. 040			Int. No. 041	1	No. 041

UNCOATED CORROSION-RESISTANT STEEL FENCES

No. 001 (T - B Lot No. 001) Gages: Int. 12 ; T - B 12
No. 002 (T - B Lot No. 002) Gages: Int. 12.5; T - B 12.5
No. 003 (T - B Lot No. —) Gages: Int. 15 ; T - B 13

PLATE I
PROCEEDINGS, AM. SOC. TESTING MATS.
VOL. 55,
REPORT OF COMMITTEE A-5:
WIRE INSPECTION REPORT

various locations. For all other groups the average state of corrosion at the last inspection is shown. The galvanized specimens are divided into the coating weight groups established originally in the test to cover galvanized wire supplied under commercial specification at that time. The detailed inspection records collected in 1953 and 1954 are presented in Table I for unfabricated wire, Table II for barbed wire, Table III for farm field fence, Table IV for chain link fence, and Table V for wire strand. These tables are similar in form to the tables in previous reports.

TABLE B.—NUMBER OF TENSILE STRENGTH SPECIMENS REMOVED FOR TESTS.

Exposure Site	Number of Wires Removed 1953 and 1954				Total Removed to Date
	Bare Steel	Zinc-Coated	Lead-Coated	Other Types	
Pittsburgh, Pa.	0	0	0	0	771
Sandy Hook, N. J.	0	0	0	0	462
Bridgeport, Conn.	0	43	0	0	435
State College, Pa.	0	0	0	0	185
Lafayette, Ind.	19	67	0	2[a]	157
All other sites	0	0	0	0	346
Total	19	110	0	2	2356

[a] Corrosion-resistant steel.

The corrosion performance of any individual specimen of barbed wire or of farm field fence listed in Tables II and III may be directly compared with the performance of specific unfabricated wire specimens listed in Table I. The Reference Information Table shows the lot numbers of wires used in fabricating all farm field fence and barbed wire samples.

At the time of inspection, records are made of the appearance of each specimen. Prior to the time of rusting, the specimens are noted as appearing "metallic" (M), "gray" (G), "yellow" (Y), etc. After rusting has begun, estimates are made of the percentage of area rusted on each specimen. The term "rust" as given in the inspection instruction states: "Rust means real rust of the base metal—ordinarily a rough corroded area."

Since some of the exposure sites had never before been visited by members of the committee, the Lafayette, Ind., site was visited in August, 1954, to inspect the wires with the newly appointed inspector. The results were in agreement with those of the previous inspector. The 12 to 14 per cent chromium steel wires at Lafayette corroded differently from those at the other sites in that they have a mottled appearance and have tiny spots of red rust scattered over their surfaces; typical examples are shown in Fig. 1.

TABLE C.—LOSS IN TENSILE STRENGTH, PER CENT PER YEAR OF EXPOSURE.

Exposure Site	No. 14½ Gage	No. 12½ Gage	No. 11 Gage	No. 9 Gage	No. 6 Gage
Pittsburgh, Pa.	15	10	7	5	3
Sandy Hook, N. J.	9	5	4	3	2
Bridgeport, Conn.	5	3	3	1	1
State College, Pa.	4	2	1	1	...
Lafayette, Ind.	3	2	2	1	1

Findings from Tension Tests:

Tension tests are made on the unfabricated wire specimens. These specimens are exposed in groups of seven taken from the same lot of wire and supposedly alike. An attempt is made to remove and test the first specimen of each group when it has been estimated to have lost 5 to 10 per cent of its strength, and the seventh specimen when it is estimated to have lost some 75 per cent of its strength. There were originally about 840 tensile strength specimens exposed at each site. The number of specimens removed to date is shown in Table B.

TABLE VII.—LOSS OF TENSILE STRENGTH SHOWN BY STEEL WIRES AFTER VARIOUS PERIODS OF EXPOSURE.[b]
Lafayette, Ind. 500 Series (14½ gage); 400 Series (12½ gage); 300 Series (11½ gage); 200 Series (9 gage); and 100 Series (6 gage) Unfabricated Wires.

Wire Lot No.	Original Breaking Load, lb	Exposure Until First Rust, yr	First Test			Second Test			Third Test			Fourth Test			Fifth Test		
			Exp. Since 1R, yr	Tensile Strength Loss		Exp. Since 1R, yr	Tensile Strength Loss		Exp. Since 1R, yr	Tensile Strength Loss		Exp. Since 1R, yr	Tensile Strength Loss		Exp. Since 1R, yr	Tensile Strength Loss	
				%	%/yr		%	%/yr		%	%/yr		%	%/yr		%	%/yr
*501[a]	500	0	1.99	13.0	6	3.08	22.0	7	4.05	25.0	6	10.92	40.0	4	17.80	54.0	3
*506	520	0	1.99	11.5	6	3.08	21.2	7	4.05	23.1	6	10.92	42.3	4	17.80	60.6	3
*507	590	0	1.99	14.3	7	3.08	21.0	7	4.05	22.6	6	10.92	42.0	4	17.80	62.2	3
510	500	5.20	12.60	42.0	3												
511	280	4.60	13.20	46.4	3												
512	320	3.90	13.90	43.8	3												
520	280	5.20	12.60	30.4	2												
521	270	5.50	12.30	31.5	2												
522	500	6.20	11.60	39.0	3												
530	310	9.90	7.90	38.7	5												
531	500	7.80	10.00	38.0	4												
540	300	11.50	6.30	28.3	4												
541	350	8.50	9.30	34.3	4												
542	510	8.50	9.30	33.3	4												
543	300	9.00	8.80	25.0	3												
551	540																
552	310																

*400a	470	0	1.99	8.4	4	3.08	10.4	3	4.05	10.4	3	10.92	21.9	2	17.80	30.2	2
*401a	440	0	1.99	10.0	5	3.08	11.1	4	4.05	12.2	3	10.92	28.9	3	17.80	43.2	2
*405	470	0	1.99	10.4	5	3.08	12.4	4	4.05	15.5	4	10.92	25.8	2	17.80	41.2	2
*406	460	0	1.99	7.4	4	3.08	8.5	3	4.05	9.6	2	10.92	23.4	2	17.80	33.0	2
410	470	4.00	13.80	14.0	1												
411	630	5.00	12.80	25.4	2												
412	840	5.00	12.80	29.8	2												
421	470	5.3	12.5	27.7	2												
422	500	5.9	11.9	19.0	2												
423	400	5.3	12.5	30.0	2												
430	780	8.3	9.5	20.5	2												
431	880	6.7	11.1	26.1	2												
432	510	10.0	7.8	15.7	2												
440	590	8.5	9.3	22.0	2												
441	520	10.6	7.2	14.4	2												
442	470	12.0	5.8	20.2	4												
443	750	9.6	8.2	20.0	2												
444	570	9.5	8.3	7.9	1												
495	750	10.8	7.0	16.7	2												
450	820																
451	510																
*300a	730	0	1.99	6.8	3	3.08	7.4	2	4.05	7.5	2	10.92	15.5	1	17.8	22.3	1
*302a	1110	0	1.99	12.3	6	3.08	13.6	5	4.05	16.4	4	10.92	25.0	2	17.8	31.0	2
*305	1070	0	1.99	7.0	4	3.08	10.1	3	4.05	10.6	3	10.92	22.1	2	17.8	27.7	2
*306	700	0	1.99	5.6	3	3.08	7.8	3	4.05	7.7	2	10.92	15.5	1	17.8	21.1	1
315	890	3.8	14.0	19.1	1												
316	1110	5.1	12.7	19.4	1												
317	780	6.4	11.4	13.5	1												
325	730	7.0	10.8	11.0	1												
326a	700	6.5	11.3	20.7	2												
327	1160	7.6	10.2	22.8	2												
329	720	6.0	11.8	31.2	3												
335	1040	7.7	10.1	12.0	1												
336	760	8.0	9.8	21.1	2												
337	860	8.0	9.8	18.6	2												
338	1020	10.8	7.0	11.7	2												
345	890	9.0	8.8	23.1	3												
346	1070	10.9	6.9	7.9	1												
347	860	12.8	5.0	11.1	2												
348	980	17.8	0.0														
350	640																
351	970																
352	1340																
397	940																

(Continued on pp. 146–147.)

TABLE VII.—*Continued.*

Wire Lot No.	Original Breaking Load, lb	Exposure Until First Rust, yr	First Test			Second Test			Third Test			Fourth Test			Fifth Test		
			Exp. Since 1R, yr	Tensile Strength Loss		Exp. Since 1R, yr	Tensile Strength Loss		Exp. Since 1R, yr	Tensile Strength Loss		Exp. Since 1R, yr	Tensile Strength Loss		Exp. Since 1R, yr	Tensile Strength Loss	
				%	%/yr		%	%/yr		%	%/yr		%	%/yr		%	%/yr
*200[a]	1010	0	1.99	9.1	5	3.08	10.9	4	10.92	19.3	2	17.80	18.7	1			
*202[a]	1640	0	1.99	8.2	4	3.08	5.2	2	10.92	--	-	17.80	23.8	1			
*205	1110	0	1.99	7.7	4	3.08	5.9	2	10.92	14.0	1	17.80	24.8	1			
*206	1480	0	1.99	7.1	4	3.08	9.5	3	10.92	17.9	2	17.80	25.7	1			
215	1200	4.0	13.8	19.6	1												
216	1630	5.2	12.6	21.2	2												
217	1080	5.0	12.8	15.3	1												
282	1320	5.0	12.8	11.7	1												
225	1650	7.9	9.9	18.2	2												
226	1150	7.9	9.9	18.7	2												
227	1640	7.9	9.9	17.7	2												
228	1080	6.0	11.8	15.3	1												
235	1680	9.5	8.3	13.7	2												
236	1270	10.0	7.8	1.6	0												
237	1540	8.2	9.6	10.1	1												
238	1650	8.0	9.8	14.3	1												
239	1120	8.7	9.1	13.8	1												
245	1570	9.9	7.9	11.8	2												
246	1190	10.9															
247	1790	9.9	7.9	20.9	3												
248	1450	11.5	6.3	6.9	1												
296	1570	12.0	5.8	8.6	1												
250	1380																
251	1940																
252	1150																
298	1520																
299	1840																

*101a *105a	2330 2750	0 0	1.99 1.99	5.7 7.2	3 4	3.08 3.08	5.2 8.0	2 3	10.92 10.92	10.6 12.7	1 1	17.8 17.8	18.6 19.0	1 1			
*102 *106	2110 2430	0 0	1.99 1.99	10.7 2.8	5 1	3.08 3.08	8.6 3.1	3 1	10.92 10.92	13.8 9.2	1 1	17.8 17.8	19.6 13.1	1 1			
115 117	2690 2230	4.2 4.6	13.6 13.2	13.0 13.2	1 1												
125 127a	1340 2540	6.0 7.8	11.8 10.0	10.3 10.8	1 1												
135 138 139	2560 1960 1920	9.5 8.8 8.0	8.3 9.0 9.8	7.8 8.2 9.6	1 1 1												
148 149	2550 1910	10.0 9.0	7.8 8.8	9.2 3.9	1 0												
151 800 801	3100 2670 1820	 16.0 17.0	 1.8 0.8														
040 041 042 043	1790 1070 670 300		 1.99	 -3.3	 0												
021 022	1640 2320																
*001 *004 *005	1230 2420 320		 17.8 17.8	 4.1 0	 0 0												
*002 *006 *007	1310 2480 280																
*003 *008 *009 015	1280 2510 290 1250																

* Uncoated wires; all other wires were zinc coated.

a Low copper content wire 0.05 to 0.08 percent copper; all other wires have approximately 0.25 percent copper.

b Summarizes data through 1954.

The test results from specimens removed during the 1953 and 1954 inspections (Table B) are included in Tables VI and VII which contain all the data accumulated to date for the bare and galvanized steel wires at Bridgeport, Conn., and Lafayette, Ind., respectively.

On the basis of tests to date, the loss in tensile strength by uncoated and zinc-coated steel wires after the wires begin to rust is shown in Table C.

Respectfully submitted on behalf of the Wire Test Inspection Committee,

FRED M. REINHART,
Chairman

REPORT OF SUBCOMMITTEE XVI

ON

FIELD TESTS OF ATMOSPHERIC CORROSION OF HARDWARE

In 1953 and 1954 only the test site at State College, Pa., was inspected. The data from these two inspections are shown in Table I. The last tabulated report of the other remaining location at Key West, Fla., appears in the 1952 Report.[1] It is planned to inspect the Florida specimens again in 1955. Tests at the other three locations have been discontinued. The last reports appear as follows:

Altoona and Brunot Island, Pennsylvania—1944

Sandy Hook, New Jersey—1952

Very little progress of corrosion is noticeable at State College. Pinhole rusting on some lead-coated samples has been rated lower in 1954 than in 1953. This is due in some instances to higher rust rating.

Respectfully submitted on behalf of the subcommittee,

A. MENDIZZA,
Chairman

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[1] *Proceedings*, Am. Soc. Testing Mats, Vol. 52, p. 118 (1952).

TABLE I.—REPORT OF INSPECTION ON HARDWARE, STRUCTURAL SHAPES, TUBULAR GOODS, ETC., EXPOSED TO ATMOSPHERE ON TEST RACKS AT STATE COLLEGE, PA.

Abbreviations and symbols used: 0, no rust; 5, 10, 25, 100, approximate percentages; R, rusting of base metal; Y, yellow or orange rust; R*, rust spots widely distributed; D, black or dark surface films (soot or rust); Tr, trace; X, 100 per cent rust listed in previous reports; TH, threads; a, samples mixed; b, average of nipple and ell; c, rust mostly on nipples only, some only on ells.

Coating	Weight, oz per sq ft of surface	4-24-53 24 yr	4-27-54 25 yr
3 BY 3 BY 5/16-IN. PLAIN STEEL ANGLES			
Hot-dip galvanized	2.52	0	TrY
Hot-dip aluminum	0.89	0	0
Electric sherardized	1.38	TrR-100Y	TrR-100Y
Lead-plated	...	10R-80R*	5R-80R*
3 BY 3 BY 5/16-IN. COPPER-BEARING ANGLES			
Hot-dip galvanized	2.88	0	TrY
Hot-dip aluminum	0.82	0	0
Electric sherardized	1.44	20R-80Y	15R-85Y
Lead-plated	...	5R-80R*	TrR-80R*
2½ BY 1½ BY 3/16-IN. PLAIN STEEL ANGLES			
Hot-dip galvanized	3.24	TrY	TrY
Hot-dip aluminum	0.75	0	0
Lead-plated	...	5R-70R*	TrR-80R*
2½ BY 1½ BY 3/16-IN. COPPER-BEARING ANGLES			
Hot-dip galvanized	2.75	0	TrY
Hot-dip aluminum	0.50	0	0
Lead-plated	...	10R-85R*	10R-70R*
2-IN. DIAMETER TUBULAR GOODS			
Electrogalvanized	1.58	0	0
Hot-dip galvanized	2.51	TrY	5Y
Hot-dip aluminum	4.73	0	0
Gas sherardized	0.66	40R-60Y	40R-60Y
Lead-plated	...	50R-50R*	35R-65R*
1-IN. TUBULAR GOODS			
Electrogalvanized	1.62	0	0
Hot-dip galvanized	1.83	Tr-85Y	TrR-85Y
Hot-dip aluminum	1.83	0	0
Electric sherardized	0.92	90R-10Y	70R-30Y
Gas sherardized	0.72	65R-35Y	60R-40Y
Calorized	...	100Y(c)	100Y(c)
Lead-plated	...	25R-70R*	15R-80R*
Amaloy	...	5R-80R*	5R-95R*
FORGED STEEL TOWER FITTINGS			
Hot-dip galvanized	2.67	40Y	60Y
Hot-dip galvanized	1.53	TrR-90Y	5R-95Y
Hot-dip aluminum	...	0	0
Electric sherardized	0.50	60R-40Y	65R-35Y

(Continued on p. 151.)

TABLE I.—*Concluded.*

Coating	Weight, oz per sq ft of surface	4-24-53 24 yr	4-27-54 25 yr
¾-IN. NIPPLES AND ELLS			
Electrogalvanized MI[a]	1.60	10R(c)	5R(c)
Electrogalvanized CI[b]	2.19	20R-TrY(c)	20R-20Y(c)
Electrogalvanized MI	2.65	55R-10Y(c)	60R-20Y(c)
Electrogalvanized CI	1.25	45R-20Y(c)	40R-40Y(c)
Hot-dip galvanized MI	1.82	TrR-85Y	TrR-100Y
Hot-dip galvanized CI	1.44	TrR-85Y	TrR-100Y
Hot-dip aluminum MI	3.20	RTH	RTH
Hot-dip aluminum CI	2.80	RTH	RTH
Electric sherardized MI	0.75	20R-80Y(c)	30R-70Y(c)
Amaloy MI and CI	...	10R-90R*	10R-90R*
TOWER CLAMPS			
Hot-dip galvanized MI	2.00	TrR-100Y	10R-90Y
Hot-dip galvanized CI	2.38	10Y	10R-10Y
Hot-dip aluminum MI	3.16	0	0
Hot-dip aluminum CI	2.51	0	0
1½ BY 1½ BY ⅛-IN. PLAIN STEEL ANGLES			
Hot-dip galvanized	3.16	TrY	TrY
Hot-dip aluminum	0.89	0	0
Lead plated	...	5R-75R*	10R-60R*
1½ BY 1½ BY ⅛-IN. COPPER-BEARING ANGLES			
Hot-dip galvanized	3.20	TrY	TrY
Hot-dip aluminum	1.11	0	0
Lead-plated	...	10R-85R*	TrR-85R*
NO. 14 BY 2½-IN. COPPER-BEARING STEEL FLATS			
Hot-dip galvanized	3.20	5Y	TrR-TrY
Hot-dip aluminum	0.47	0	0
Lead plated	...	TrR-70R*	TrR-45R*
KNOCKOUT BOXES			
Hot-dip galvanized	1.50	TrR-20Y	TrR-35Y
Electric sherardized	0.28	100Y	100Y-TrR
Amaloy	...	5R-90R*	5R-90R*
Hot-dip aluminum	1.84	0	0
BULLDOG CLAMPS			
Hot-dip aluminum	1.35	0	0
¼ BY 3-IN. PLAIN STEEL FLATS			
Hot-dip galvanized	2.49	TrY	TrY
Hot-dip aluminum	0.90	0	0
Lead-plated	...	10R-85R*	TrR-50R*
¼ BY 3-IN. COPPER-BEARING FLATS			
Electrogalvanized	0.84	90R-10Y	80R-20Y
Hot-dip galvanized	2.67	TrY	TrY
Hot-dip aluminum	0.66	0	0
Lead-plated	...	TrR-90R*	TrR-55R*
NO. 792 WINDOW FRAME SECTION			
Hot-dip galvanized	2.60	0	TrY
Hot-dip aluminum	1.39	0	0

[a] MI = malleable iron.
[b] CI = cast iron.

REPORT OF COMMITTEE A-6
ON
MAGNETIC PROPERTIES*

Committee A-6 on Magnetic Properties held two meetings during the year: on June 4, 1954, during the Annual Meeting of the Society in Chicago, Ill., and on March 2, 1955, in Middletown, Ohio, as guests of the Armco Steel Corp.

During the past year there has been activity in Subcommittee II on Methods of Sampling and Test, and in the Editorial Subcommittee, which has resulted in changes in all but one of the standards presently under the jurisdiction of Committee A-6. There has also been activity in the working groups, particularly in the working group set up to study and revise the Standard Method of Test for Alternating Current Core Loss and Permeability of Magnetic Materials (A 343–54) and in the group preparing a manual of magnetic testing.

At the meeting in June, 1954, R. L. Sanford of the National Bureau of Standards and B. M. Smith of the General Electric Co. announced their retirement from the committee. Both have given excellent service to the committee for many years.

REVISIONS OF STANDARDS, IMMEDIATE ADOPTION

The committee recommends for immediate adoption revisions of the following standards as appended hereto[1] and accordingly asks for the necessary nine-tenths affirmative vote at the Annual Meeting in order that the revisions may be referred to letter ballot of the Society:

Standard Methods of:

Testing Magnetic Materials (**A 34 – 53**),[2] and
Test for Normal Induction and Hysteresis of Magnetic Materials (**A 341 – 49**).[3]

Standard General Specifications for:

Flat-Rolled Electrical Steel (**A 345 – 49**).[3]

The revision of Standard Specifications A 345 consists of its consolidation with Tentative Specifications A 345 – 54 T, A 378 – 54 T, and A 379 – 54 T which, as stated later in this report, are recommended for withdrawal.

WITHDRAWAL OF TENTATIVES

Because of consolidation with the Standard General Specification for Flat-Rolled Electrical Steel (A 345 – 49), the committee recommends that the following tentatives be withdrawn:

Tentative Specifications for:

Flat-Rolled Grain Oriented Electrical Steel, 3 Per Cent Silicon Content, in Cut Lengths or Coils (**A 378 – 54 T**),[4]
Flat-Rolled Electrical Steel, 3.5 to 5 Per Cent Silicon Content, in Cut Lengths or Coils (**A 379 – 54 T**),[4] and
Flat-Rolled Electrical Steel (**A 345 – 54 T**).[4]

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* Presented at the Fifty-eighth Annual Meeting of the Society, June 26–July 1, 1955.

[1] The revised standards appear in the 1955 Book of ASTM Standards, Part 1.

[2] 1953 Supplement to Book of ASTM Standards, Part 1.

[3] 1952 Book of ASTM Standards, Part 1.

[4] 1954 Supplement to Book of ASTM Standards, Part 1.

REAPPROVAL OF STANDARDS

The committee recommends the reapproval of the following four standards:

Standard Definitions of:

Terms, with Symbols, Relating to Magnetic Testing (**A 340 – 49**).

Standard Methods of Test for:

Permeability of Feebly Magnetic Materials (**A 342 – 53**),
Alternating Current Core Loss and Permeability of Magnetic Materials (**A 343 – 54**), and
Electrical and Mechanical Properties of Magnetic Materials (**A 344 – 52**).

EDITORIAL CHANGES

The committee recommends editorial changes in the following three standards:

Standard Definitions of Terms, With Symbols, Relating to Magnetic Testing (A 340 – 48):[3]

Change the definition for lamination factor to read: "The ratio of the volume of a solid mass, assuming a definite density based on chemical composition, to the volume of the stack of laminations under a given pressure. To express as a percentage, multiply by 100."

Standard Methods of Test for Alternating Current Core Loss and Permeability of Magnetic Materials (A 343 – 54):[4]

Section 3(b).—In the first sentence change the words "14 g per centimeter of length of test strips" to read "12 strips."

Change the fifth sentence to read: "The following table based on 36 g per centimeter of length of test strips gives the total number of strips of the thicknesses most frequently used to fill this requirement:

Strip Thickness, in.	Gage No.[a]	Number of Strips
0.0310	22	20
0.0280	23	24
0.0250	24	24
0.0220	25	28
0.0185	26	36
0.0170	27	36
0.0155	28	40
0.0140	29	44
0.01250	30	48
0.0110	31	58"

[a] These gage numbers are those given in the Electrical Sheet and Strip Gage Table.

Standard Methods of Test for Electrical and Mechanical Properties of Magnetic Materials (A 344 – 52):[3]

Section 31(a).—In the first sentence change the maximum test lot size from the present "5000 kg (11,000 lb)" to read "5500 kg (12,000 lb)."

The recommendations in this report have been submitted to letter ballot of the committee, the results of which will be reported at the Annual Meeting.[5]

This report has been submitted to letter ballot of the committee, which consists of 28 voting members; 22 members returned their ballots, of whom 21 have voted affirmatively and 0 negatively.

Respectfully submitted on behalf of the committee,

A. C. BEILER,
Chairman.

M. P. GETTING, JR.,
Secretary.

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[5] The letter ballot vote on these recommendations was favorable; the results of the vote are on record at ASTM Headquarters.

REPORT OF COMMITTEE A-7
ON
MALLEABLE IRON CASTINGS*

Committee A-7 on Malleable Iron Castings held two meetings during the year: the first at Chicago, Ill., on June 18, 1954, and the second at Cincinnati, Ohio, on February 1, 1955.

Due to the pressure of business, L. W. Kattelle resigned from active work with Committee A-7 during the current year. Mr. Kattelle, a long-time member of the committee, contributed much from his experience to the furtherance of important matters that have been before the committee. His decision to retire was accepted with regret, but the committee is pleased to have J. J. Curran as Mr. Kattelle's successor.

At the present time the committee consists of 54 members, of whom 27 are classified as producers, 15 as consumers, and 12 as general interest members.

REVISION OF STANDARD AND REVERSION TO TENTATIVE

The committee recommends that the Standard Specification for Pearlitic Malleable Iron Castings (**A 220 - 51**)[1] be revised as follows and reverted to tentative status. This revision is recommended in the light of the advances made in the production and use of the various grades of pearlitic malleable castings.

TABLE I.—TENSILE REQUIREMENTS.[a]
(Revision of Table I, Specification A 220.)

	Grade 45010	Grade 45007	Grade 48004	Grade 50007	Grade 53004	Grade 60003	Grade 80002
Tensile Strength, min, psi[b]	65 000	68 000	70 000	75 000	80 000	80 000	100 000
Yield Point or Yield Strength, min, psi[b]	45 000	45 000	48 000	50 000	53 000	60 000	80 000
Elongation in 2 in., min, per cent	10	7	4	7	4	3	2

[a] Typical Brinell hardness number ranges of the grades of material in this table are as follows:

Grade	Typical Brinell Hardness Number Range
45010	163 to 207
45007	163 to 217
48004	163 to 228
50007	179 to 228
53004	197 to 241
60003	197 to 255
80002	241 to 269

[b] It is recognized that higher tensile and higher yield strengths may be obtained from any of the grades of material in the table by the use of a conventional quench-and-temper treatment.

Table I.—Change to read as shown in the accompanying Table I.

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* Presented at the Fifty-eighth Annual Meeting of the Society, June 26–July 1, 1955.

[1] 1952 Book of ASTM Standards, Part 1.

The recommendation in this report has been submitted to letter ballot of the committee, the results of which will be reported at the Annual Meeting.[2]

This report has been submitted to letter ballot of the committee, which consists of 54 members; 39 members returned their ballots, of whom 35 have voted affirmatively and 0 negatively.

Respectfully submitted on behalf of the committee,

W. A. KENNEDY,
Chairman.

JAMES H. LANSING,
Secretary.

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[2] The letter ballot vote on this recommendation was favorable; the results of the vote are on record at ASTM Headquarters.

REPORT OF COMMITTEE A-10

ON

IRON-CHROMIUM, IRON-CHROMIUM-NICKEL, AND RELATED ALLOYS*

Committee A-10 on Iron-Chromium, Iron-Chromium-Nickel, and Related Alloys held meetings at Chicago, Ill., on June 16, 1954, during the Annual Meeting of the Society, and on February 2, 1955, at Cincinnati, Ohio, during ASTM Committee Week.

The committee consists of 105 members, of whom 45 are classified as producers, 42 as consumers, and 18 as general interest members.

NEW TENTATIVE

The committee recommends that the Recommended Practice for Conducting Acidified Copper Sulfate Test for Intergranular Attack in Austenitic Stainless Steels be accepted for publication as tentative as appended hereto.[1]

REVISIONS OF TENTATIVES

The committee recommends revisions of the following tentatives as indicated:

Tentative Recommended Practice for Boiling Nitric Acid Test for Corrosion-Resisting Steels (A 262 - 52 T):[2] Revise by the addition of the Electrolytic Oxalic Acid Etching Test as appended hereto.[3]

Tentative Specifications for Seamless and Welded Austenitic Stainless Steel Pipe (A 312 - 54 T):[4] The revision, recommended jointly with Committee A-1 on Steel, is set forth in the Report of Committee A-1.[5]

ADOPTION OF TENTATIVES AS STANDARD WITHOUT REVISION

The committee recommends that the following tentative specifications be approved for reference to letter ballot of the Society for adoption as standard without change:

Tentative Specifications for:

Corrosion-Resistant Iron-Chromium and Iron-Chromium-Nickel Alloy Castings for General Application (**A 296 - 49 T**),[2]
Heat-Resistant Iron-Chromium and Iron-Chromium-Nickel Alloy Castings for General Application (**A 297 - 49 T**),[2]
Chromium-Nickel Corrosion-Resisting Steel Spring Wire (**A 313 - 47 T**),[2]
Corrosion-Resisting Steel Billets and Bars for Reforging (**A 314 - 47 T**),[2] and
Stainless Steel Wire Strand (**A 368 - 53 T**).[6]

REVISIONS OF STANDARDS, IMMEDIATE ADOPTION

The committee recommends for immediate adoption revisions of the following standards and accordingly asks for the necessary nine-tenths affirmative vote at the Annual Meeting in order that the revisions may be referred to letter ballot of the Society:

Standard Specification for Hot-Rolled and Cold-Finished Corrosion-Resisting Steel Bars (A 276 - 54):[4]

Table II.—Change Footnote *b* to read

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* Presented at the Fifty-eighth Annual Meeting of the Society, June 26–July 1, 1955.

[1] The new tentative appears in the 1955 Book of ASTM Standards, Part 1.

[2] 1952 Book of ASTM Standards, Part 1.

[3] The revised tentative appears in the 1955 Book of ASTM Standards, Part 1.

[4] 1954 Supplement to Book of ASTM Standards, Part 1.

[5] See p. 89.

[6] 1953 Supplement to Book of ASTM Standards, Part 1.

as follows:

[b] For some specific products, it may not be practicable to use a 2-in. gage length. In the case of rounds from 0.500-in. to 0.125-in. diameter inclusive, a gage length equal to four times the diameter may be used. For shapes other than rounds having a cross-sectional area of 0.2 sq in. or less, the test may be made in full section using a gage length equal to 4.5 times the square root of the cross-sectional area.

Revisions for immediate adoption in the following standards are recommended jointly with Committee A-1 on Steel, and the revisions are set forth in the Report of Committee A-1:[5]

Standard Specifications for Seamless and Welded Ferritic Stainless Steel Tubing for General Service (A 268 – 54),[4]

Standard Specifications for Seamless and Welded Austenitic Stainless Steel Tubing for General Service (A 269 – 54),[4]

Standard Specifications for Seamless and Welded Austenitic Stainless Steel Sanitary Tubing (A 270 – 54),[4] and

Standard Specifications for Seamless Austenitic Chromium-Nickel Steel Still Tubes for Refinery Service (A 271 – 54).[4]

EDITORIAL CHANGES

The committee recommends that in Standard Specifications for Hot-Rolled and Cold-Finished Corrosion-Resisting Steel Bars (**A 276 – 54**) and wherever reference is made in any of the specifications under the jurisdiction of Committee A-10 to Types 304L and 316L, a footnote be added to read as follows:

NOTE.—For some applications, the substitution of Type 304L for Type 304, or Type 316L for Type 316 may be undesirable because of design, fabrication, or service requirements. In such cases, the purchaser should so indicate on the order.

The recommendations in this report have been submitted to letter ballot of the committee, the results of which will be reported at the Annual Meeting.[7]

ACTIVITIES OF SUBCOMMITTEES

Subcommittee IV on Methods of Corrosion Testing (F. L. LaQue, chairman).—The supplement to Specification A 362 to permit the use of the electrolytic oxalic acid etch test for screening specimens prior to the boiling nitric acid test received committee approval by letter ballot.

The Recommended Practice for Descaling and Cleaning Stainless Steel Surfaces (A 380), which was prepared by a task group under E. G. Holmberg, was accepted by the Society and appears in the 1954 Supplement to Book of ASTM Standards, Part 1.

A task group under K. M. Huston completed a recommended procedure for conducting the acidified copper sulfate test for intergranular attack in austenitic stainless steels which is appended hereto for Society approval.[1]

Under the chairmanship of C. P. Larrabee, a task group has made an inspection of the special stainless steel specimens which have been exposed at atmospheric test locations in Pittsburgh and New York City. A report of this inspection is appended hereto.[8]

A subgroup under the chairmanship of J. B. Henry, Jr., has made another inspection of several typical architectural applications of stainless steels. The results of these inspections are summarized in a report which also is appended hereto.[9]

Progress has been made in arrangements for procuring specimen materials for the large-scale program of atmospheric tests of stainless steels. It is expected that the tests will be under way by the latter part of 1955.

A task group under the chairmanship of F. L. Bloom has been appointed to survey current research programs on stress corrosion of stainless steels. The results of this survey will determine whether any specific activity by the subcommittee should be undertaken in this field.

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[7] The letter ballot vote on these recommendations was favorable; the results of the vote are on record at ASTM Headquarters.

[8] See p. 160.

[9] See p. 169.

F. L. LaQue has submitted his resignation as chairman of this subcommittee.

Subcommittee V on Mechanical Testing (R. Heyer, chairman).—A list of 18 changes in mechanical test specimens and methods for Specifications A 167, A 176, A 177, and A 240 was approved by letter ballot of Committee A-10 prior to the June, 1954, meeting. Several editorial revisions resulting from discussion at this meeting will also be included in the revised specifications.

One of these changes was the introduction of the 8-in. gage length test specimen for plates. Designation of elongation requirements for tests using the 8-in. gage length specimen have not been made because of lack of test data upon which to establish such requirements. These data are being accumulated by Subcommittee V and will be turned over to Subcommittee IX for use in revising the product specifications. Meanwhile, Subcommittee IX is to determine the need for the 8-in. gage length specimen.

At the February, 1955, meeting, the Task Group on Tension Testing reported excellent agreement in tension test results at two laboratories on annealed, $\frac{1}{4}$ hard, and $\frac{1}{2}$ hard type 301, tested at a constant strain rate of 0.4 in. per in. per min. Additional tests will now be made at strain rates of 0.3 and 0.5 in. per in. per min in order to determine the effect of small changes in strain rate on the tensile strength and elongation. If the results of these tests are in substantial agreement in the two laboratories, additional tests will be made at a slower strain rate.

A change in the wording of Footnote *b* of Table II of Specification A 276 was recommended in order to provide a method for determining the gage length of shapes, other than rounds, having cross-sectional areas of 0.2 sq in. or less. This change has been submitted to letter ballot of the committee.

Subcommittee VIII on Specifications for Wrought Products (R. B. Gunia, chairman).—During the past year, this subcommittee took action to adopt as standard Tentative Specifications A 313 – 47 T, A 314 – 47 T, and A 368 – 53 T.

Action was also taken to clarify the specimen shape and size for determination of elongation in certain products covered in Specifications A 276 – 54.

A task group to investigate the necessity for preparing specifications for the newly developed chromium-manganese austenitic alloys is currently reviewing that problem.

Subcommittee IX on Specifications for Flat Products (G. W. Hinkle, chairman). —Several changes have been made in Specifications A 167, A 176, A 177, and A 240, bringing these specifications up to date. These include a change of tensile properties on type AISI 430, the inclusion of type 305 in Specifications A 167 and A 240, and the inclusion of types 304L and 316L with physical requirements in Specifications A 240. On Specifications A 167, A 176, and A 240, there has been a clarification of alternate methods for determining yield strength. The physical properties for types 403 and 410 in Specifications A 176, and A 240 have been clarified so that they now agree.

A "Basis of Purchase" section has been approved for Specifications A 167, A 176, and A 177. In Specifications A 240, sensitizing tests for types 321 and 347 have been established as to procedure and number of tests per shipment.

A task group has been appointed to work on revision of Specification A 240 to meet new Boiler Code requirements.

Subcommittee X on Specifications for Castings (J. J. Kanter, chairman) is recommending the adoption of Specifications A 296 and A 297 to standards without any changes. Action was taken also to continue Specification B 190 - 50 in its present form.

Subcommittee XII on Specifications for High-Temperature Super-Strength Alloys (L. L. Wyman, chairman).—The three task groups handling the different classes of alloys have completed the initial assignment of preparing the prototype patterns detailing those items which should be specified for each class of material. These groups have proceeded to the succeeding step—that of compiling the several lists of specific alloys which fall into each classification. This is preliminary to the specification writing.

The task group on alloy compilation has brought the alloy list up-to-date, and this current edition is now available as *ASTM STP No. 170.* The present compilation lists all alloys known, even though some appear to be dropping into disuse. Also, both old and new designations are used, and some foreign alloys listed. A new compilation has been planned for next year to include the ferritic alloys.

The task group on scope has prepared a definition of "super-strength alloys" in terms of both austenitic and ferritic (martensitic) materials. The statement was unanimously accepted at the last subcommittee meeting and has been circulated for letter ballot.

Joint A-1, A-10 Subcommittee on Stainless Tubing Specifications (J. J. B. Rutherford, chairman).—The Task Group appointed to study insertion of heat-treating clauses into appropriate specifications has submitted proposals to Committee A-10, Subcommittee IX, for appropriate action. Proposals made by the task group regarding definition of lengths in Specification A 312 were approved unanimously for submission to the parent committees for letter ballot.

The task group appointed to clarify the supplementary requirements of Specifications A 106, A 312, and A 335 is requesting Subcommittee IX of A-1 to withdraw the supplementary requirements in Specifications A 312 because of Specification A 376 which contains these requirements. The attention of the subcommittee was directed toward Specification A 358 covering stainless pipe for elevated-temperature service and which has resolved the previously discussed subject of the "Finish" clause for stainless pipe. Mention was made of the formation of a special subgroup to prepare a specification for light-wall welded stainless steel pipe in sizes up to and including 30-in. outside diameter. The status of specifications under jurisdiction of the Joint Subcommittee emphasized that several specifications pertaining to stainless steel tubular products prepared in Committee A-1 have not been reviewed in Committee A-10. Committee A-1 is being requested to share jurisdiction of Specifications A 249, A 276, and A 358 with Committee A-10. It was noted that Specification A 213 contains both stainless and regular steel compositions and might therefore be divided into two separate specifications. The subcommittee requested assistance in resolving the problem pertaining to the promulgation of stainless steel tubing specifications within the Society without reference to the committees formulated to handle stainless steel products.

This report has been submitted to letter ballot of the committee; 108 ballots have been returned, of which 102 have been voted affirmatively and 1 negatively.

Respectfully submitted on behalf of the committee,

JEROME STRAUSS,
Chairman.

M. A. CORDOVI,
Secretary.

APPENDIX I

REPORT OF TASK GROUP ON INSPECTION OF CORROSION-RESISTANT STEELS IN ARCHITECTURAL AND STRUCTURAL APPLICATIONS

The major installations examined included those previously reported in the Symposium on Atmospheric Weathering of Corrosion-Resistant Steels[1] and also reinspected by the committee membership in 1948.[2] Other reports appeared in 1939[3] and 1949.[4]

In addition, several new buildings erected since 1948 in the Pittsburgh area were examined. The Universal Pictures Building in New York, erected in 1947, as well as several additional installations in Philadelphia were also included.

A summary of the observations follows:

525 William Penn Place Building, Pittsburgh, Pa:

This building incorporates type 302, 18 per cent chromium - 8 per cent nickel, spandrel panels and windows. The spandrel panels are one piece stamped from No. 2B finish sheet. The windows are brake or roll formed from No. 2B finish sheet or No. 2 finish cold-rolled strip. The interior of the building incorporates considerable No. 4 finish sheet in the lobby wall paneling, some type 430 17 per cent chromium and some type 302 stainless steel. The building was erected in 1950–1951 and was occupied in March, 1951. The exterior metal components were reportedly washed down shortly after occupancy. The exterior panels had a considerable amount of dirt deposits on the lateral surfaces of the stamped design. Removal of this dirt indicated a very fine, almost unnoticeable, pitting in some locations. There were some spots where the plastic protective coating which had been used on the exterior metal had not been entirely removed. Also, in the corners of some of the panel framings on the ground level, very mild reddish discoloration was noted under which very fine pitting could be seen on close examination. Because of the extensive excavation and construction work in the area, dirt conditions have been very bad, and it has been impossible to keep the building clean. This work is now being completed, and it is intended that the building be completely washed down. In general, the exterior spandrel assemblies show no indication of corrosive attack.

Also examined were the parapet flashings and the coping on the 41st floor roof level, also of No. 2B finish, type 302 sheet. These areas which are continually washed by wind and rain were very bright and showed no indication of corrosive attack.

The windows were examined from the interior of the building, and no indication of any corrosion on interior or exterior was noted except that heavy brownish deposits had collected on the window sills under the bottom sash. Under these deposits at the 17th floor, very fine pits were discernible. The interior stainless steel in the lobbies, elevator doors and cabs, cafeteria, and kitchens were briefly observed and were, of course, in excellent condition. During the entire inspection, the committee was accompanied by the building manager.

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[1] *Proceedings*, Am. Soc. Testing Mats., Vol. 46, p. 593 (1946).

[2] *Proceedings*, Am. Soc. Testing Mats., Vol. 48, p. 137 (1948).

[3] *Proceedings* , Am. Soc. Testing Mats., Vol. 39, p. 197 (1939).

[4] *Proceedings*, Am. Soc. Testing Mats., Vol. 49, p. 138 (1949).

Gateway Buildings, Pittsburgh, Pa:

Construction on buildings Nos. 2 and 3 was started in 1951 and was completed in 1952. Building No. 1 was completed in 1953. The entire exterior surfaces are 17 per cent chromium, type 430, No. 2 dull finish cold-rolled strip or sheet. Close examination of the panel surfaces was possible only from the ledge at second-floor level and from the roof. At the second-floor level, the spandrel panels in some instances showed purple-brown splotches. These were most prevalent on the eastern faces of the north and south wings and the eastern faces of the east wing as well as the northern and southern faces of the east wing. The condition appeared to lessen at successively higher floors and to disappear completely at about the eighth floor on all three buildings. The fourth spandrel panel of building No. 3, north wing, eastern exposure was thoroughly cleaned using a scouring powder recommended expressly for stainless steel. The deposits were not heavy, but underneath the splotches fine pitting was observed. Some discoloration was also observed on the spandrel panels directly under the window sills where the metal is sheltered, and upon cleaning with the powder, very fine pitting was also apparent at these points. At one location on the roof near soldered joints, rusting was noticed, very obviously caused by incomplete removal of soldering flux at the time of assembly. Except in the locations noted, the balance of the exterior surfaces presented a bright, clean appearance without evidence of discoloration or corrosive attack. The cause of the noted discoloration is not known. Shortly after the erection of buildings Nos. 2 and 3, considerably heavy rust streaking was noted, and analysis of deposits at that time indicated the presence of appreciable amounts of chlorides in the deposits. The present rusting is most prevalent on those areas which are not scoured by prevailing winds and rain and which are protected by adjacent buildings. The rusting may be associated with a chloride condition of unknown source or may possibly be associated with incomplete removal of the latex type of adhesive that was used on the paper protection of the panels during fabrication and erection. There was no evidence of presence of any adhesive, however, during the panel cleaning, and application of carbon tetrachloride alone had no effect upon the discolored surfaces. Streaking of some of the pier and corner cover panels was observed, apparently because of drainage from the interior of the concrete backing of the next higher panels.

The store fronts and street level facia are constructed of No. 4 finish, 14 gage, type 430 sheet. They are reportedly cleaned about every three months with a mild cleaning powder and presented a very good appearance, free from any evidence of corrosion. Two recessed doorways on building No. 1 facing on Duquesne Way, however, had apparently not been cleaned for a considerable length of time and exhibited a very light rust film over the entire surface. These surfaces should also be cleaned at whatever intervals are necessary to prevent such superficial discoloration. These particular doorways represent a very severe type of atmospheric exposure in that the surfaces are never subject to the washing and cleaning action of wind and rain.

Heppenstall Building, Pittsburgh, Pa:

The renovation of this four-story office building in a heavy industrial district was completed in 1952. An existing masonry structure was completely sheathed in uninsulated 18 gage, type 442 (21 per cent straight chromium), No. 2 finish cold-rolled strip panels. In company with Heppenstall personnel, the building was completely examined from the ground level. At two isolated locations small reddish-colored discolorations were noticeable, and on closer examination and removal of the deposits, very fine pitting was discovered to have occurred in the metal. One of these locations had not been cleaned at the time the building was erected. The exact cause of the discoloration in both locations is not known, but the most likely possibility is, of course, that chlorides may have come in contact with the metal, possibly through cleaning of the surrounding masonry with muriatic acid. The coping and part of the flashing on the roof were also type 442, and no indications of rusting or discoloration whatever were noted in those locations.

Part of the roof at the time of renovation had been replaced with a sloping standing seam roof of type 430, No. 2 bright finish cold-rolled strip or sheet. The roof was reportedly thoroughly cleaned down with a stainless steel cleaning powder and flushed with water, but several months after installation, rust spots were reportedly observed. These spots are still apparent on many of the roofing panels, but removal of the dirt and discoloration reveals that only very fine pitting has occurred underneath the red spots. One panel which was thoroughly recleaned over a year ago has shown no recurrence of the spotting. One possible theory is that the spots were caused by deposition of fine particles of metallic iron deposited from the atmosphere.

The entrance doors and canopy were constructed using type 430, No. 4 finish sheet. Some evidence of light superficial rusting was noticeable on the vertical areas, but considerable light general superficial rusting had occurred on the underside horizontal surface of the canopy, with many very fine pits underneath when the surface was cleaned of deposits.

Allegheny Ludlum Steel Corp. Research Laboratory, Brackenridge, Pa.:

A two-story laboratory building, constructed using prefabricated insulated panels with textured type 302 exterior surfaces, and a one-story small gas storage building using No. 2B finish prefabricated panels were occupied in 1951. At the time of erection the buildings were completely cleaned of any dirt attendant to erection. Since that time no general cleaning has been done. There is no evidence of corrosion whatsoever on any of the stainless steel surfaces, although it was reported that some rusting and fine pitting had appeared at the window heads on the front first-floor level. These deposits were analyzed and found to be high in chlorides. It is assumed that the rusting was caused by seepage of water containing calcium chloride which was probably used at the time of erection during the winter to melt ice from the floors. Since cleaning over six months ago, no additional rusting has occurred. Some rusting was also apparent in one or two locations where apparently carbon-steel screws had been used instead of stainless.

These buildings are located about a half mile from the main Allegheny Ludlum Steel Corp.'s Brackenridge Plant. The hilltop location permits free access of the prevailing westerly winds so that the atmosphere is not so highly contaminated as at the other Pittsburgh building locations.

Empire State Building, New York, N. Y.

This building, erected in 1931, was inspected in company with representatives of the building management. The 18 gage, No. 6 finish, uninsulated type 302 mullions were examined on all exposures at the sixth-floor offset. All of the mullions had a dark adherent dirt deposit that was more prevalent on the exposures that are protected by adjacent buildings or not subject to the sweep of the prevailing winds. When the dirt deposits were cleaned from the mullions, extremely fine pitting was observable upon very close inspection. On the 85th floor observation deck, the guard railings, which are of type 302 stainless steel and which were erected in 1949, were examined. All of those parts, which are subject to handling by visitors, were bright and shiny, whereas those portions that are not accessible had an adherent dark dirt deposit spread uniformly on the metal. From the 89th floor level, the pilasters on the tower were examined closely. Although they had never been cleaned since their erection, they were completely free of dirt or any discoloration. No evidences of pitting whatsoever were observable; in fact the finish appeared to be altered not at all from the original mill finish.

From all indications, practically no corrosive attack has occurred on the metal in the 23-year service period. Although all of the mullions have an adherent grime deposit—to a greater or lesser extent depending upon the amount of washing from the elements—which appears quite gray and dark at close inspection, it is interesting to note that at a distance the mullions shine and sparkle on the sunny side of the building.

Universal Pictures Building, New York, N. Y.:

This building was completed in 1947 and incorporates a considerable amount of No. 4 finish, type 302, 12 gage store front and other metal work at the entrances, as well as 12 gage, type 302 mullion covers on the higher floors. The building was examined in company with the building superintendent. The metal work on the ground floor was in excellent shape with no evidence of any pitting or corrosive attack. It is reportedly cleaned weekly, using a mild powder cleaner.

At the 21st and 17th floor offsets, all of the mullion covers showed rather large, very shallow light gray pits. The building superintendent was unable to give any information on how long this condition might have existed or what might be its possible cause. There was no sign of any rusting whatsoever nor were the mullions covered with any sort of deposit. At one location on the 17th floor, there were several irregular patches which showed no evidence of any such pitting and which appeared to have the original No. 4 finish. It was the concensus of the committee that at one time these mullion covers must have been subject to some strong pitting agent, such as muriatic acid or calcium chloride, and that at that time some discoloration probably occurred which had later been washed away by weathering. The building superintendent said it was his understanding that at one time the stonework of the building had been cleaned, but the building management did not verify this statement, stating that no cleaning had ever been done on the building exterior at the upper level.

The surface condition in no way interferes with the serviceability of the panels since the pitting is very shallow and is not observable from ground level. It is expected that no additional pitting will occur if the panels are subject only to normal weathering from the atmosphere, but it will be interesting to re-examine these panels several years hence.

Chrysler Building, New York, N. Y.:

This building was inspected in company with the building superintendent. The exterior first three floors incorporate No. 4 finish, type 302 stainless steel. This metal was in good condition with no evidence of any corrosive attack. It is cleaned twice a year using a proprietary mild cleaning powder. Formerly No. 6 pumice and turpentine were used.

The tower surfaces of type 302 stainless steel sheet, erected in 1929–1930, were examined through the windows at the 71st floor level. The surface was very black due to an adherent grime deposition, but, upon cleaning, the surface appeared to be substantially in the same condition as when erected with only extremely light pits being observable. On the type 302 window sills, there were appreciable reddish deposits under which some pitting was noticeable upon cleaning. Samples of these deposits were taken and found to contain over 2 per cent chlorides.

At the base of the tower on the 61st floor, the tower surfaces of type 302 were examined closely. The gargoyles had a bright smooth shiny surface with no evidences of corrosive attack or pitting. The tower surfaces were quite dark due to the deposited grime, but almost no indications of pitting were discernible upon cleaning. It was interesting to note that on the tower, in locations where fins had been applied by soldering, the metal surface was bright and unpitted and not heavily coated with the adherent grime as were the other surfaces. This is reportedly because the sheets as erected had a light oil film which was removed only where thorough cleaning was employed to remove all traces of soldering flux.

As at the higher level, at the 31st floor level offset the ornamental figures at the corners were clean and free of any evidence of corrosion. On the coping there were some light rust spots, apparently caused by splashing of some foreign material. Upon cleaning, very fine pits were observed under these reddish discolorations. It is assumed that with normal weathering these spots will disappear, leaving only the very fine pitted condition which in no way impairs the serviceability or appearance of the coping.

Boardwalk Installations, Atlantic City, N. J.:

Many store fronts and canopy installations of No. 4 finish stainless steel were examined for about a mile on either side of the Haddon Hall Hotel. Such exposure is extremely corrosive to any metal, since the buildings are subject quite frequently to direct salt spray from the nearby surf. The metal in most instances was one of the 18 per cent chromium - 8 per cent nickel grades, probably type 302, although in one or two locations type 430 had been used. Many of the establishments examined had been closed during the winter and were either just being opened or were still closed at the time of the inspection in early April.

Two of the locations previously reported upon in the earlier inspection, the duPont Exhibit Building and the Apollo Theater, were revisited. At the duPont Exhibit Building, some minor rusting was evident on the store front sections at the top. It was reported that these had not been cleaned since the spring of 1953 The other stainless steel surfaces appeared to be in good condition with no indication of superficial rusting. The maintenance man reported that the doors were cleaned every two weeks, the ceiling every three months, and the stainless steel sign on the front of the building was cleaned every month.

At the Apollo Theater, the manager reported that the old marquee had been removed in 1949. The stainless steel ceiling in the entrance way which had been installed about 20 years ago still remains. It is No. 4 finish, 18 per cent chromium - 8 per cent nickel, probably 24 gage. It was reportedly cleaned every 10 days using mild abrasive proprietary scouring powder. However, the ceiling sheets are embossed with grooves, and apparently the bottoms of these grooves had not been thoroughly cleaned for some time since heavy red rust deposits existed therein. Several of these grooves were cleaned by committee members, using special stainless steel cleaning powder, and heavy pitting was found to exist in the grooves after removal of the surface deposits. In some instances these pits had progressed completely through the metal.

A large number of other installations were examined. In general, it was found that where the metal surfaces were not cleaned regularly to remove salt spray deposits rusting and pitting occurs to an extent depending upon the frequency of cleaning and the extent of natural washing by wind and rain. Rusting on surfaces that were not cleaned regularly occurred more profusely in protected areas—on the undersides of canopies, the horizontal surfaces of block sign letters, and in crevices. A brief listing of some of the installations observed follows:

Vi-de-Lan Store.—18 per cent chromium - 8 per cent nickel, No. 4 finish. Widespread rusting under canopy. Bad pitting in spots and in crevices. Vertical surfaces not nearly so bad as horizontal. Probably not cleaned since fall of 1953.

1115 Boardwalk.—No. 4 finish, canopy ceiling. Slight rusting with no indication of rusting on vertical 18 per cent chromium - 8 per cent nickel surfaces.

1113 Boardwalk.—Riddle Building.—No. 4 finish, type 302. In good condition with no indication of rusting or pitting. Apparently cleaned frequently.

Madeira Lace Shop.—Type 302, No. 4 finish surfaces in good condition. Reportedly cleaned twice weekly. Installed several years previously.

1221 Boardwalk.—Type 302 store front window frames in good condition except at the top where light rusting was apparent. This presumably was not cleaned so frequently as the balance of the frame.

1235 Boardwalk.—Type 302 store front window frames installed in March, 1953. Reportedly cleaned weekly the year round. No rusting or pitting apparent.

1237 Boardwalk.—Same type of installation as 1235 Boardwalk and installed at same time. Reportedly cleaned every three weeks the year round. Slight rusting apparent.

1403 Boardwalk.—Mayflower Hotel.—Stainless steel doors as well as vertical type 302, No. 4 finish surfaces, easily accessible from boardwalk level, in good condition. Horizontal surfaces on canopy exhibited light general rusting. A representative of the hoted stated that cleaning of the doors and vertical surfaces was done every two weeks. Frequency of cleaning of the canopy under surface not known.

Shelburne Hotel.—Type 302, No. 4 finish boardwalk canopy rusted underneath, particularly at crevices where water tends to collect. Canopy on the side entrance away from the boardwalk was in better condition but showed some slight rusting on the underneath surfaces.

James Candy Store.—Store front and sign installed about April 1, 1953. Reportedly cleaned twice weekly with hot water only. In very good condition. The sign letters reportedly had not been cleaned since installation and exhibited a light over-all rusting.

Tides Restaurant.—Stainless steel store front installed 1947. Protected during the winter season when the restaurant is closed by coating with a heavy grease in the fall at closing time. Reportedly cleaned at least once a week in season. Appeared to be in good condition.

Howard Johnson Restaurant.—Reportedly installed about 1945 and cleaned every one and one half weeks during the summer season. Frequency of cleaning in the winter questionable. Showed general light superficial rusting.

Boardwalk Cafeteria—1007 Boardwalk.—Incorporates both type 302 and type 430, No. 4 finish store front and entrance. Had been closed apparently all winter with no grease protection. General superficial rusting on type 430 somewhat worse than on type 302.

Beyda, Fifth Ave.—1207 Boardwalk.—Has stainless steel block letter sign and flat store front section of No. 4 finish, type 302. Installed about 1949. Reportedly cleaned three times yearly and cleaned last about six months prior to this inspection. Flat vertical surfaces were in good condition with very light scattered superficial rust spots. The insides of the block stainless steel letters were appreciably rusted, cleaning on these surfaces being done only once every year.

One of the local fabricators who reportedly does much of the installation of stainless steel work on the boardwalk was visited by the task group and was asked whether his company ever used type 316, mentioning the considerably better corrosion resistance to seacoast atmospheric conditions of type 316 molybdenum-bearing 18 per cent chromium - 8 per cent nickel. Although the fabricator had no knowledge of the advantages of type 316 in this respect, he indicated that he would consider its use in future installations.

Also examined during the time in Atlantic City were a number of installations several blocks back from the boardwalk where apparently impingement of salt spray would not occur. There, no rusting or pitting on such installations was observed.

Philadelphia Savings Fund Society Building, Philadelphia, Pa.:

The building was erected in 1932. The inspection was made in company with the assistant building manager. In the sun room on the 53rd floor, considerable straight chromium stainless steel (type 430 or possibly type 410) bar stock was used in the window frame construction interior. All such metal was in good condition with no indication of any rusting or surface discoloration. A small amount of type 302 in exterior window sections in the sun room was bright with no indication of any corrosion or pitting. A straight chromium bar section on one window location on the exterior showed a very light superficial rusting.

The kitchens for the executive dining room, also at this level, were examined. These had been in service since 1932. The type 302 sinks, work surfaces, steam table tops, etc., showed no signs of pitting and had the expected bright shiny surface appearance. Also inspected were a number of type 302 kettles which had been in service for that same period of time, the bottoms of which showed only very light, isolated, small pits. Considerable type 302 stainless steel was used elsewhere in the interior of the building for railings, column covers, escalators, and a large 12-gage wall panel made up of 2 by 6-ft flat sections. Finish was generally No. 4, and appearance was excellent with no indication of any discoloration or corrosive attack. The vaults were also visited. The entire exterior surfaces are straight chromium stainless steel, presumably type 410, No. 4 finish. All surfaces were in excellent shape and were reportedly wiped every three months to prevent finger marking, using a light oil supplied by the vault manufacturer.

Considerable No. 4 finish, type 302 was used on the exterior entrances and for the sign. The doors and accessible parts of the entrances are wiped daily with ammonia water and cleaned monthly with whiting. All such surfaces were in excellent condition. The letters of the sign were reportedly probably not cleaned since December, 1953, but inspection from ground level showed no indication of superficial discoloration or rusting.

The ceiling of the subway entrance leading from the sidewalk into the building basement is type 302 stainless steel and exhibited appreciable light surface superficial discoloration. Upon investigation, the building manager found that this was not cleaned by his staff, and it was his opinion that cleaning had undoubtedly been neglected on these areas for some time. He stated that steps would be taken to have this area cleaned at such intervals as would be necessary to avoid appearance of light superficial rusting which tends to occur on protected surfaces that are not washed by the elements.

Pennsylvania Building—1500 Chestnut St., Philadelphia, Pa.:

This building incorporates a considerable amount of No. 4 finish, type 302 on the window sections and the entrances. Erection was completed in 1949. The metal exhibited a very good appearance generally, but upon very close inspection some discoloration was noticeable at joints under the entrance canopies, on the undersides of some of the window frame sections, and on the inside of the smaller block letters. Cleaning is done by a window-cleaning concern, generally using water only and probably with no attention to thorough cleaning of the metal components. The committee recommended to the building manager that an occasional cleaning with suitable powder cleaner be applied to the stainless steel components in those areas where light superficial rusting was discernible.

The Reading Railroad "Crusader" Stainless Steel Train:

This train constructed of type 301, 17 per cent chromium - 7 per cent nickel, No. 2 finish cold-rolled strip was fabricated by the Edward G. Budd Co. and has been in continuous service since 1937 except for two brief intervals. It has made two round trips daily between Philadelphia and Jersey City except for a four-month period in the spring of 1952 when the train was disassembled completely for thorough inspection, and for a period of several months in 1946 while the train was being repaired following a derailment.

The inspection was made in the Reading Terminal in company with railroad representatives and a representative of the Budd Co.

The sides of the cars are washed every night, one day with water only and the following day with an alkaline cleaning solution. This has been employed since 1948, replacing an acid-type cleaner that was formerly used. The inspection revealed no indication of pitting or rusting whatsoever on the sides of the cars. The roof of one car was also closely examined. Since the roofs of the cars are cleaned only once a month, a light layer of surface grime was present but there were no indications of any surface attack or pitting, and removal of the surface dirt revealed the metal underneath to be smooth and unaffected during its continuous service life of almost 17 years.

The committee was given a copy of the report of inspection at the time the cars were completely disassembled for thorough inspection in March, 1952. The only evidences of corrosion discovered at that time occurred on the corrugated roof under the letterboards where considerable pitting and perforations up to $\frac{1}{4}$ in. in diameter had occurred. These were reported to have resulted because of the lack of bedding compound behind the letterboard plates, this condition resulting in accumulation of cleaning acids which became concentrated by repeated collection and drying to a point where corrosive attack occurred. These damaged areas were replaced, and it is anticipated that through the use of bedding compound and alkaline cleanings, rather than acid ones, similar trouble will not occur in the future.

It was also reported that the self-tapping screws, reportedly hardened type 410 12 per cent chromium, used in installing the side linings were corroded at the time of inspection and could not be removed except by chipping off the heads. On reassembly similar screws were reportedly used, but the committee's inspection only by visual examination from the exterior could discern no indication of rusting or corrosive attack on the screw heads.

GENERAL OBSERVATIONS AND RECOMMENDATIONS OF THE COMMITTEE

1. The 18 per cent chromium - 8 per cent nickel and 17 per cent chromium - 7 per cent nickel grades are entirely adequate from the standpoint of atmospheric corrosion resistance in urban and industrial locations. Type 442 is also adequate although only one such installation was inspected. Type 430 is also apparently entirely acceptable where metal surfaces are vertical and subject to the scouring action of wind and rain. In locations not subject to the normal cleaning action of the elements, type 430 and to a lesser extent, types 302 and 442 may require occasional cleaning to avoid light superficial rusting.

2. In marine environments, the 18 per cent chromium - 8 per cent nickel grades will give satisfactory service in architectural installations if cleaned frequently to avoid superficial rusting. Type 430 will also give satisfactory service, but it must be cleaned more frequently than the 18 per cent chromium - 8 per cent nickel grades. The molybdenum-bearing 18 per cent chromium - 8 per cent nickel grade (type 316) should give even more satisfactory service than the nonmolybdenum-bearing grades because of its superior corrosion resistance to chloride solutions.

3. Designs incorporating horizontal surfaces which are not subject to the scouring action of the elements should be avoided because dirt and corrosive materials tend to collect thereon.

4. Crevices that are not free-draining of moisture should be avoided.

5. After erection, stainless steel surfaces should be completely cleaned of all foreign matter.

6. Chlorides should be kept from contact with stainless steel surfaces during or after erection, since superficial rusting and pitting will occur unless chlorides are removed within a relatively short period of time.

7. If coatings are used on stainless steel for protection during fabrication and erection, they should be readily removable and completely removed promptly after erection.

Respectfully submitted on behalf of the task group,

J. B. HENRY, JR.,
Chairman.

APPENDIX II

REPORT OF TASK GROUP ON INSPECTION OF NICKEL-BEARING AND NONNICKEL-BEARING STAINLESS STEELS

1954 INSPECTION

Nine grades of stainless steel, each in No. 2B and No. 4 finish, were exposed on the roof of the Williams and Co. building in North Side, Pittsburgh, Pa., on May 20, 1953, and on the roof of the Port of Authority Building in New York, N. Y., on July 10, 1953. The results of the inspection on May 17 and 18, 1954, are recorded below.

At both inspections the left half of each sheet was cleaned with a paste of Steel Brite and water. The faying surfaces that were bolted together were examined, as well as the entire sheet. In this report the removable piece is referred to as No. 1, the piece spot-welded to the bottom half as No. 2, and the bottom section as No. 3. The inspection results of W. G. Renshaw, Research Laboratory, Allegheny Ludlum Steel Corp., given below, seem typical of the careful inspection. In future reports a table showing the range of gradations by the several inspectors will be submitted.

Pittsburgh, Pa.:

Position No. 1—Type 410, No. 4 Finish.—There were some pits at the faying surface when dismantled to be cleaned. Numerous yellow spots were observed before cleaning. The sample was cleaned well, revealing many fine pits on the surface. There was heavy rust on all the protected surfaces on the underside of the samples.

Position No. 2—Type 410, No. 2B Finish.—There were many yellow spots on the uncleaned surfaces. Many fine pits were evident after cleaning. Sample No. 3 showed a yellow film near the trough on the uncleaned side. There was heavy rust on the underside of the samples.

Position No. 3—Type 430, No. 4 Finish.—There were no pits on sample No. 1 after cleaning, although there was faint indication of some yellow spots on sample No. 2. There were a few pits observed about 1 in. above the trough on the cleaned side of No. 3 and some yellow spots in the same position before cleaning. There was heavier rust around spot welds on the underside than in the vicinity of bolts.

Position No. 4—Type 430, No. 2B Finish. There were a few etched and pitted spots near the bottom of section No. 1. Some indication of yellow spots (8 to 10) on section No. 2 was apparent. Cleaned and uncleaned areas of section No. 3 were similar to No. 1 and No. 2, respectively. The underside was similar to the sample at position No. 3.

Position No. 5—Type 442, No. 4 Finish.—A few etched and pitted spots were noted on section No. 1 after cleaning and some yellow spots on section No. 2. Some rust was found in the vicinity of spot welds on the underside, but very little at bolts.

Position No. 6—Type 442, No. 2B Finish.—No pitting was noted after cleaning. These samples looked very good except for a few yellow spots on section No. 2. The underside was the same as samples in position No. 5.

Position No. 7—Type 446, No. 4 Finish.—Similar to type 442. There are some marks that appear to be pits near the lower edge of section No. 1. Type 446 was similar to type 442 on the uncleaned side and on the underside.

Position No. 8—Type 446, No. 2B Finish.

—Section No. 1 appeared to be very good after cleaning. All other sections seemed good also. The underside was about the same as type 442.

Position No. 9—Type 301, No. 4 Finish.—Section No. 1 showed some scattered fine pits when cleaned. Otherwise, the samples looked excellent. The underside showed some rusting in the vicinity of spot welds but practically none near bolts.

Position No. 10—Type 301, No. 2B Finish.—All sections looked very good. The underside was about the same as that seen in position No. 9.

Position No. 11—Type 304, No. 4 Finish.—Section No. 1 showed a few fine pits just starting. A possible few small yellow spots were noted on section No. 2. Section No. 3 showed some fine pits about 1 to 1½ in. from the trough on the left side. The underside was similar to type 301 samples.

Position No. 12—Type 304, No. 2B Finish.—All sections looked very good. The underside was the same as type 301.

Position No. 13—Type 17-4-6, No. 4 Finish.—Section No. 1 showed a few pits, some of which were visible before cleaning. There was yellow staining in a line about 2 to 3 in. above the trough on the uncleaned side (right side) of section No. 3. There was rust in the vicinity of spot welds on the underside but practically none near bolts.

Position No. 14—Type 17-4-6, No. 2B Finish.—There was no indication of attack on sections Nos. 1 and 2. The No. 3 section showed yellow spots 2 to 3 in. above the trough on the uncleaned side. The underside was the same as position No. 13.

Position No. 15—Type 16-1-17, No. 4 Finish.—Section No. 1 showed 20 to 30 scattered pits when cleaned. There was considerable pitting at the trough and 2 to 3 in. above it on section No. 3. Rusting was noted on the bottom.

Position No. 16—Type 16-1-17, No. 2B Finish.—Some pits were noted near the bottom of panel No. 1. Numerous pits were in the trough and 1 in. up from the trough on the clean side of section No. 3. The underside was the same as position No. 15.

Position No. 17—Type 13-1-18, No. 4 Finish.—A few fine pits were observed on the clean side (panel No. 1). On panel No. 3 some spotty stains were not completely removed by cleaning. There were also yellow spots in a 1-in. wide streak about 1 to 2 in. from the trough on the uncleaned side of panel No. 3. The underside showed rusting all over the surface.

Position No. 18—Type 13-1-18, No. 2B Finish.—Some scattered fine pits were noted after cleaning. Yellow spots were scattered on panel No. 2. The long No. 3 section showed the same 1-in. wide streak of yellow stains as the No. 4 polish finish. The underside was the same as position No. 17.

In general, the specimens at Pittsburgh showed appreciable deposits of dirt. The unusual condition of heavier rust near spot welds than bolts on the underside cannot be explained. Cleaning with Steel Brite has a tendency to scratch, and a milder cleanser is to be obtained for next year's inspection.

New York, N. Y.:

Position No. 1—Type 410, No. 4 Finish.—There were numerous (several hundred) pits visible on panel No. 1 after cleaning. It was necessary to use Steel Brite to remove the yellow spots since Bon Ami was not sufficient. Many yellow spots were visible before cleaning. Heavy rusting was observed on the underside. There was one pit on the faying surface at the crevice.

Position No. 2—Type 410, No. 2B Finish.—Numerous pits were visible after cleaning section No. 1 and the left half of section No. 3. Many yellow spots were found on the uncleaned sample. It was necessary to use Steel Brite for cleaning. There was heavy rusting on the underside.

Position No. 3—Type 430, No. 4 Finish.—No rusting or pitting was observed. The specimen was cleaned satisfactorily with Bon Ami.

Position No. 4—Type 430, No. 2B Finish.—This was the same as type 430, No. 4 finish.

Position No. 5—Type 442, No. 4 Finish.—No pitting, staining, or rusting was seen on the top or the underside.

Position No. 6—Type 442, No. 2B Fin-

ish.—This was the same as the No. 4 finish except that two yellow spots were discovered on the top side of panel No. 2.

Position No. 7—Type 446, No. 4 Finish.—The top and underside were free of pitting and rusting.

Position No. 8—Type 446, No. 2B Finish.—The condition on the top was good. There was rust at one scratch on panel No. 3, and some rust near spot welds on the underside.

Position No. 9—Type 301, No. 4 Finish.—The condition on the top and underside was very good.

Position No. 10—Type 301, No. 2B Finish.—The condition was good on all surfaces.

Position No. 11—Type 304, No. 4 Finish.—All of the top and under surfaces were good. One very large oil spot which held dirt was seen near the upper right of panel No. 2.

Position No. 12—Type 304, No. 2B Finish.—All the top surfaces were in good condition. There was one large oil spot near the center top of panel No. 3. On the underside, some slight rusting appeared near spot welds only.

TABLE I.—INSPECTION OF STAINLESS STEEL PANELS AT PITTSBURGH, PA.

Exposed: May 20, 1953. Inspected: May 23, 1955.

Material	Finish	General Appearance			Gutter		Faying Surfaces		Spot Welds	Bolt Holes[a]
		Skyward		Groundward						
		Before Cleaning	After Cleaning	Before Cleaning	Before Cleaning	After Cleaning	Before Cleaning	After Cleaning		
Type 410	No. 4 No. 2B	No Y	E	BR	OK	E	Y	OK	Y	OK
Type 430	No. 4 No. 2B	No Y	E	OK	OK	OK	OK	OK	Y	OK
Type 442	No. 4 No. 2B									
Type 446	No. 4 No. 2B									
Type 301	No. 4 No. 2B									
Type 304*	No. 4 No. 2B									
17-4-6	No. 4 No. 2B									
16-1-17	No. 4 No. 2B									
13-1-18	No. 4 No. 2B									

[a] Bolt holes no worse than general condition of groundward surface.

* Least stained of any spot welds.

OK—No visible attack.

Y—Yellow stains.

R—Red rust.

E—Etched.

B—As prefix to R, indicates about 30 per cent of the area so designated.

TABLE II.—INSPECTION OF STAINLESS STEEL PANELS AT NEW YORK, N. Y.
Exposed: July 10, 1953. Inspected: May 24, 1955.

Material	Finish	General Appearance			Gutter		Faying Surfaces		Spot Welds	Bolt Holes	Remarks
		Skyward		Groundward							
		Before Cleaning	After Cleaning	Before Cleaning	Before Cleaning	After Cleaning	Before Cleaning	After Cleaning			
Type 410	No. 4	>100 P + Y	P	BY, BR	P + Y	P	Y	OK	R	OK	Pits, possibly 0.01 to 0.02 in. in diameter.
	No. 2B										
Type 430	No. 4	No Y	OK	OK	No Y	OK	No Y	OK	OK	OK	Has best over-all appearance.
	No. 2B										
Type 442	No. 4										
	No. 2B										
Type 446	No. 4										
	No. 2B										
Type 301	No. 4										
	No. 2B										
Type 304	No. 4										
	No. 2B										
17-4-6	No. 4										
	No. 2B										
16-1-17	No. 4	No Y	OK	Some Y	No Y	OK	No Y	OK	R	OK	Has best over-all appearance.
	No. 2B	No Y	OK	OK	No Y	OK	No Y	OK	R	OK	
13-1-18	No. 4	No Y	OK	Some Y	No Y	OK	No Y	OK	R	Y	
	No. 2B	No Y	OK	Some Y	Y	Y	No Y	OK	R	Y	

OK—No visible attack.
Y—Yellow stains.
R—Red rust.
P—Pits.
B—As prefix to Y or R, indicates about 30 per cent of the area so designated.

Position No. 13—Type 17-4-6, No. 4 Finish.—All the top surfaces were in good condition. There were some yellow spots on the underside.

Position No. 14—Type 17-4-6, No. 2B Finish.—All top surfaces were in good condition. One etched spot was noted near the center of panel No. 3. Some yellow spots were present on the underside.

Position No. 15—Type 16-1-17, No. 4 Finish.—Some fine pits were noted after cleaning panel No. 1. Scattered yellow spots were also noted on panel No. 2. There was staining near the right edge and at the trough on the uncleaned (right) side of panel No. 3. Some pitting was seen at the trough on the cleaned side. These panels were rusted on the bottom.

Position No. 16—Type 16-1-17, No. 2B Finish.—Some pits appeared to be starting on cleaned panel No. 1, and yellow spots were visible on section No. 2. There were yellow stains and pitting at ½ to 1 in. from the trough. Some rusting occurred near the bolts and spot welds on the underside.

Position No. 17—Type 13-1-18, No. 4 Finish.—A few yellow spots were visible on the uncleaned areas of sections Nos. 2 and 3. Some of these were concentrated near the edges and at the trough on long panel No. 3. There was rusting on the underside.

Position No. 18—Type 13-1-18, No. 2B Finish.—A few yellow spots were noted on the uncleaned surfaces. There was rusting on the underside.

In general, the specimens at New York did not show nearly so much attack as those at Pittsburgh. The dirt film was considerably lighter at this location. There was much less evidence of the contrasting behavior between spot-welded areas and bolted areas in the New York City panels.

The location on the Port of Authority Building appears to be undesirable because of oil which splashes on the specimens from helicopters landing and taking off within 50 ft of the exposure racks. Although no attempt to count oil spots was made, mention of several large ones is made in the sample descriptions.

1955 INSPECTION

The task group has made the second annual inspection of the sheets of nine grades of stainless steel, each in No. 2B and No. 4 finish, exposed in Pittsburgh, Pa., and New York, N. Y. The sheets had a much better appearance than at the first inspection last year. The yellow stains that were prevalent on several sheets in 1954 had disappeared. There was somewhat more dirt on the sheets at Pittsburgh than on those at New York City, and the oil spots (noted in 1954 at New York City) were not so numerous. A detergent type of household cleaner was used on the left half of each sheet. After washing off the cleaner with water, the appearance of most of the sheets was practically the same as when the sheets were exposed. The detailed results of the inspections are given in Tables I and II.

Respectfully submitted on behalf of the task group,

C. P. LARRABEE,
Chairman.

REPORT OF COMMITTEE B-1
ON
WIRES FOR ELECTRICAL CONDUCTORS*

Committee B-1 on Wires for Electrical Conductors held three meetings during the year: one in Washington, D. C., on October 26, 1954; one in New York, N. Y., on January 25, 1955; and one at the Society's headquarters in Philadelphia, Pa., on April 1, 1955. Meetings of the Advisory Subcommittee, and of Subcommittees II, IV, and VII also were held during the year.

The subcommittees' organization and their chairmen remain unchanged, except that the resignation from the committee of J. B. Dixon, due to a change in work assignment, left a vacancy in the chairmanship of Subcommittee II, which subsequently was filled by R. H. Lloyd.

The committee notes with regret the retirement on February 1, 1955, of E. P. Hall, a long-time member of the committee who contributed much to its work. Mr. Hall will be followed by the committee's best wishes in his new consulting work.

The committee now consists of 79 members, of whom 40 are classified as producers, 26 as consumers, and 13 as general interest members.

NEW TENTATIVE

With the rapid growth of the electronics industry, there has been increasing usage of silver-plated copper wires for high-temperature applications. However, there has been no uniformity of specification requirements among the various groups of users, including the Military. The committee recognized the need of standardization efforts in this field about two years ago and since then has developed a proposed specification through a task group whose membership was representative of the various interests in this field. The committee, therefore, recommends for publication as tentative the proposed Specifications for Silver-Coated Soft or Annealed Copper Wire, as appended hereto.[1]

REVISIONS OF TENTATIVES

The committee recommends that the following two specifications be revised as indicated and continued as tentative:

Tentative Specifications for Hard-Drawn Aluminum Wire for Electrical Purposes (B 230 - 54 T):[2]

Section 11(a).—Revise the second sentence to read: "Joints may be made in rod or in the wire prior to final drawing by electrical butt-welding or by cold pressure-welding in accordance with the best commercial practice."

Section 11(b).—Revise the first sentence to read: "If agreed upon between the manufacturer and the purchaser, joints may be made during final drawing or in the finished wire by electrical butt-welding or by cold pressure welding, with the following provisions:"

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* Presented at the Fifty-eighth Annual Meeting of the Society, June 26–July 1, 1955.

[1] The new tentative appears in the 1955 Book of ASTM Standards, Part 2.

[2] 1954 Supplement to Book of ASTM Standards, Part 2.

Tentative Specifications for Concentric-Lay-Stranded Aluminum Conductors, Steel-Reinforced (ACSR) (B 232 - 53 T):[3]

Section 4(a).—Revise the first sentence to read: "Electric butt-welds or cold pressure-welds in the finished individual aluminum wires composing the conductor may be made during the stranding process."

Section 8(a).—Revise the present Section 8(a) to read as follows:

> (a) The breaking strength of the completed conductor shall be taken as that percentage, indicated below, of the sum of the ultimate breaking strengths of the aluminum wires, calculated from their nominal diameter and the appropriate specified minimum average tensile strength given in Table I of ASTM Specifications B 230 plus the sum of the values for stress at 1 per cent extension under load for the zinc-coated steel wires, calculated from their nominal diameter and the appropriate specified minimum stress at 1 per cent extension given in Table I of ASTM Specifications B 245. For conductors composed of 1 steel and 18 aluminum wires, the percentage of total aluminum wire strength taken shall be 95 per cent. For conductors composed of other combinations of steel and aluminum wires, the percentage of total aluminum wire strength taken shall be 100 per cent.

Table I.—Add to the present Table I, in proper size sequence, new conductor sizes and strandings, to read as shown in the accompanying Table I.

TABLE I.—CONDUCTOR SIZES AND STRANDINGS.

(Additions to Table I, Specifications B 232.)

Conductor Size (Aluminum)		Stranding			
		Aluminum		Steel	
cir mils	Awg	Number of Wires	Diameter, in.	Number of Wires	Diameter, in
636 000....	...	24	0.1628	7	0.1085
556 500....	...	24	0.1523	7	0.1015
477 000....	...	24	0.1410	7	0.0940
477 000....	...	18	0.1628	1	0.1628
397 500....	...	18	0.1486	1	0.1486
336 400....	...	18	0.1367	1	0.1367
266 800....	...	18	0.1217	1	0.1217

Delete from the present Table I conductor sizes and strandings, as shown in the accompanying Table II.

TABLE II.—CONDUCTOR SIZES AND STRANDINGS.

(Deletions from Table I, Specifications B 232.)

Conductor Size (Aluminum)		Stranding			
		Aluminum		Steel	
cir mils	Awg	Number of Wires	Diameter, in.	Number of Wires	Diameter, in.
900 000....	...	54	0.1291	7	0.1291
666 600....	...	54	0.1111	7	0.1111
636 000....	...	54	0.1085	7	0.1085
605 000....	...	30	0.1420	19	0.0852
605 000....	...	26	0.1525	7	0.1186
605 000....	...	54	0.1059	7	0.1059
300 000....	...	26	0.1074	7	0.0835

Table III.—Add to the present Table III, in proper sequence, new strandings and increments, to read as follows:

Stranding of ACSR, Number of Wires		Increment (Increase), per cent		
		Weight		Electrical Resistance
Aluminum	Steel	Aluminum	Steel	
18......	1......	2.0	0	2.0
24......	7......	2.5	0.4	2.5

Table IV.—Revise the present Table IV to read as shown in the accompanying Table III.

TENTATIVES CONTINUED WITHOUT REVISION

The committee recommends that the following nine specifications be continued as tentative without revision:

Tentative Specifications for:

Hard-Drawn Copper Wire (**B 1 - 53 T**),
Soft or Annealed Copper Wire (**B 3 - 54 T**),
Tinned Soft or Annealed Copper Wire for Electrical Purposes (**B 33 - 53 T**),
Lead-Coated and Lead-Alloy-Coated Soft Copper Wire for Electrical Purposes (**B 189 - 53 T**),
Tinned Hard-Drawn and Medium-Hard-Drawn Copper Wire for Electrical Purposes (**B 246 - 51 T**),

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[3] 1953 Supplement to Book of ASTM Standards, Part 2.

TABLE III.—RECOMMENDED SHIPPING LENGTHS FOR STANDARD SIZES OF ALUMINUM CONDUCTORS STEEL REINFORCED.

(For Information Only)

(Revisions in Table IV, B 232.)

Conductor Size, cir mils or Awg	Stranding		Weight per 1000 ft, lb	Nominal Length of Each Piece, ft	Nominal Weight of Each Length, lb
	Aluminum	Steel			
1 590 000	54 × 0.1716	19 × 0.1030	2044	2310	4722
1 510 500	54 × 0.1673	19 × 0.1004	1942	2435	4729
1 431 000	54 × 0.1628	19 × 0.0977	1840	2570	4729
1 351 500	54 × 0.1582	19 × 0.0949	1737	2720	4725
1 272 000	54 × 0.1535	19 × 0.0921	1635	2885	4717
1 192 500	54 × 0.1486	19 × 0.0892	1533	3080	4722
1 113 000	54 × 0.1436	19 × 0.0862	1431	3300	4722
1 033 500	54 × 0.1384	7 × 0.1384	1331	3855	5131
954 000	54 × 0.1329	7 × 0.1329	1229	4170	5125
874 500	54 × 0.1273	7 × 0.1273	1126	4555	5129
795 000	30 × 0.1628	19 × 0.0977	1235	3855	4761
795 000	26 × 0.1749	7 × 0.1360	1094	3590	3927
795 000	54 × 0.1214	7 × 0.1214	1024	5010	5130
715 500	30 × 0.1544	19 × 0.0926	1111	4290	4766
715 500	26 × 0.1659	7 × 0.1290	985	3985	3925
715 500	54 × 0.1151	7 × 0.1151	921	5575	5135
636 000	30 × 0.1456	19 × 0.0874	988	4810	4752
636 000	26 × 0.1564	7 × 0.1216	875	4490	3929
636 000	24 × 0.1628	7 × 0.1085	819	6260	5127
556 500	30 × 0.1362	7 × 0.1362	872	3965	3457
556 500	26 × 0.1463	7 × 0.1138	766	5125	3926
556 500	24 × 0.1523	7 × 0.1015	717	7145	5123
477 000	30 × 0.1261	7 × 0.1261	747	4635	3462
477 000	26 × 0.1355	7 × 0.1054	657	5975	3924
477 000	24 × 0.1410	7 × 0.0940	615	8340	5129
477 000	18 × 0.1628	1 × 0.1628	518	5700	2953
397 500	30 × 0.1151	7 × 0.1151	623	5555	3461
397 500	26 × 0.1236	7 × 0.0961	547	7180	3927
397 500	18 × 0.1486	1 × 0.1486	432	6840	2955
336 400	30 × 0.1059	7 × 0.1059	527	6565	3460
336 400	26 × 0.1138	7 × 0.0885	463	8470	3922
336 400	18 × 0.1367	1 × 0.1367	365	8080	2949
266 800	26 × 0.1013	7 × 0.0788	367	5340	1960
266 800	18 × 0.1217	1 × 0.1217	290	5100	1479
266 800	6 × 0.2109	7 × 0.0703	342	4975	1701
0000	6 × 0.1878	1 × 0.1878	291.1	4285	1247
000	6 × 0.1672	1 × 0.1672	230.8	5400	1246
00	6 × 0.1490	1 × 0.1490	183.1	6800	1245
0	6 × 0.1327	1 × 0.1327	145.2	8575	1245
1	6 × 0.1182	1 × 0.1182	115.2	5405[a]	623
2	7 × 0.0974	1 × 0.1299	106.7	8950	955
2	6 × 0.1052	1 × 0.1052	91.3	6825[a]	623
3	6 × 0.0937	1 × 0.0937	72.4	8620[a]	624
4	7 × 0.0772	1 × 0.1029	67.0	7145[a]	479
4	6 × 0.0834	1 × 0.0834	57.4	10870[a]	624
5	6 × 0.0743	1 × 0.0743	45.5	13700[a]	623
6	6 × 0.0661	1 × 0.0661	36.1	17240[a]	622

TABLE III.—*Continued.*

HIGH-STRENGTH CONDUCTORS

Conductor Size, cir mils or Awg	Stranding		Weight per 1000 ft, lb	Nominal Length of Each Piece, ft	Nominal Weight of Each Length, lb
	Aluminum	Steel			
211 300	12 × 0.1327	7 × 0.1327	527.5	8360	4410
203 200	16 × 0.1127	19 × 0.0977	676.8	7675	5194
190 800	12 × 0.1261	7 × 0.1261	476.3	4630	2205
176 900	12 × 0.1214	7 × 0.1214	441.4	4995	2205
159 000	12 × 0.1151	7 × 0.1151	396.8	5555	2204
134 600	12 × 0.1059	7 × 0.1059	336.0	6565	2206
110 800	12 × 0.0961	7 × 0.0961	276.6	7175	1985
101 800	12 × 0.0921	7 × 0.0921	254.1	8680	2206
80 000	8 × 0.1000	1 × 0.1670	149.0	5415	807

[a] Normally shipped 2 lengths per reel.

Standard Nominal Diameters and Cross-Sectional Areas of AWG Sizes of Solid Round Wires Used as Electrical Conductors (**B 258 – 51 T**),

Soft or Annealed Coated Copper Conductors for Use in Hookup Wire for Electronic Equipment (**B 286 – 54 T**),

Tentative Method of:

Determination of Cross-Sectional Area of Stranded Conductors (**B 263 – 53 T**), and

Test for Stiffness of Bare Soft Square and Rectangular Copper Wire for Magnet Wire Fabrication (**B 279 – 53 T**).

ADOPTION OF TENTATIVES AS STANDARD WITHOUT REVISION

The committee recommends that the following six specifications be approved for reference to letter ballot of the Society for adoption as standard without revision. These specifications have stood for two or three years as tentative, during which time no criticisms or suggestions for improvement of a material nature have been received.

Tentative Specifications for:

Rope-Lay-Stranded Copper Conductors Having Bunch-Stranded Members, for Electrical Conductors (**B 172 – 53 T**),[3]

Rope-Lay-Stranded Copper Conductors Having Concentric-Stranded Members, for Electrical Conductors (**B 173 – 53 T**),[3]

Bunch-Stranded Copper Conductors for Electrical Conductors (**B 174 – 53 T**),[3]

Standard Weight Zinc-Coated (Galvanized) Steel Core Wire for Aluminum Conductors, Steel Reinforced (ACSR) (**B 245 – 52 T**),[4]

Zinc-Coated (Galvanized) Steel Core Wire (With Coatings Heavier than Standard Weight) for Aluminum Conductors, Steel Reinforced (ACSR) (**B 261 – 52 T**),[4] and

Three-Quarter Hard Aluminum Wire for Electrical Purposes (**B 262 – 52 T**).[4]

REVISIONS OF STANDARDS, IMMEDIATE ADOPTION

The committee recommends for immediate adoption revisions in the following seven standards, and accordingly asks for the necessary nine-tenths affirmative vote at the Annual Meeting in order that these revisions may be referred to letter ballot of the Society for adoption as standard.

Standard Specifications for Bronze Trolley Wire (B 9 – 53):[3]

Incorporate into the specifications the proposed revisions listed under Editorial Note. Revise the proposed new Section 10(*e*) to include after the second sentence of the second paragraph, a new sentence reading: "Samples shall be clean and ends free from burrs."

Standard Specifications for Copper Trolley Wire (B 47 – 52):[4]

Incorporate into the specifications the proposed revisions listed under Editorial

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[4] 1952 Book of ASTM Standards, Part 2.

Note. Revise the proposed new Section 10(*c*) to include after the second sentence of the second paragraph a new sentence reading: "Samples shall be clean and ends free from burrs."

Figure 1.—In the tabular headings for area and weight, editorially change the present reference to Note 7 in three locations to read Note 5.

Standard Specifications for Soft Rectangular and Square Bare Copper Wire for Electrical Conductors (B 48 – 52):[4]

Section 5.—Renumber the present Section 5(*a*), 5(*b*), 5(*c*), and 5(*d*), together with the heading "Tensile Properties," to read Section 7(*a*), 7(*b*), 7(*c*), and 7(*d*), respectively.

Add a new Section 5 titled "Standard Reference Temperature" to read as follows:

> 5. For the purposes of these specifications, all wire dimensions and properties shall be considered as occurring at the internationally standardized reference temperature of 20 C (68 F).

Section 6.—Renumber the present Section 6(*a*) and 6(*b*), together with the heading "Bending Properties," to read Section 8(*a*) and 8(*b*), respectively.

Add a new Section 6 titled "Standard Rules for Rounding Off" to read as follows:

> 6. All calculations for the standard nominal dimensions and properties of rectangular and square wires shall be rounded off in the *final* value only, in accordance with the rounding-off method of the Recommended Practices for Designating Significant Places in Specified Limiting Values (ASTM Designation: E 29).

Section 7.—Renumber the present Section 7, together with the heading "Resistivity," to read Section 12(*a*).

Add a new Section 12(*b*) to read as follows:

> (*b*) Nominal resistances and other values derived from the resistivity units shall be calculated from the nominal wire dimensions in accordance with the following formulas and all values so derived shall be rounded off in the *final* value only, in accordance with Section 6, to the same number of significant figures as used in expressing the nominal dimensions, but in no case to less than three significant figures:
>
> $$\text{D-c resistance at 20 C, ohms per 1000 ft} = \frac{8.1458 \times 10^3}{A}$$
>
> $$\text{D-c resistance at 20 C, ohms per lb} = \frac{2.1135 \times 10^6}{A^2}$$
>
> $$\text{D-c resistance at 20 C, ft per ohm} = 0.12277 \times A$$
>
> $$\text{D-c resistance at 20 C, lb per ohm} = 0.47315 \times A^2 \times 10^{-6}$$
>
> where:
>
> A = The nominal cross-sectional area of the wire in square mils, obtained in accordance with Section 10.

Section 8.—Renumber the present Section 8(*a*), 8(*b*), 8(*c*), 8(*d*), and 8(*e*), together with the heading "Dimensions and Permissible Variations," to read Section 9(*a*), 9(*b*), 9(*c*), 9(*d*), and 9(*e*), respectively.

Section 9.—Renumber the present Section 9, together with the heading "Density," to read Section 13.

Section 10.—Renumber the present Section 10, together with the heading "Finish," to read Section 14.

Add a new Section 10 titled "Nominal Cross-Sectional Areas" to read as follows:

> 10. Nominal cross-sectional areas in square mils shall be calculated by subtracting the area reductions due to rounded corners or rounded edges (see Tables II and III of the Explanatory Notes) from the product of the specified nominal thickness and width dimensions in mils (0.001 in.). Values so derived shall be rounded off in accordance with Section 6 to the same number of significant figures as used in expressing the nominal dimensions, but in no case to less than three significant figures.

Section 11.—Renumber the present Section 11(*a*), 11(*b*), and 11(*c*), together with the heading "Packing and Shipping," to read Section 15(*a*), 15(*b*), and 15(*c*), respectively.

Add a new Section 11 titled "Nominal Weight and Length" to read as follows:

11. Nominal weights and lengths shall be calculated from the nominal wire dimensions in accordance with the following formulas and shall be rounded off in the *final* value only, in accordance with Section 6, to the same number of significant figures as used in expressing the nominal dimensions, but in no case to less than three significant figures:

$$\text{Weight, lb per 1000 ft} = 3.8540 \times A \times 10^{-3}$$

$$\text{Length, ft per lb} = \frac{0.25947 \times 10^{6}}{A}$$

where:

A = nominal cross-sectional area of the wire in square mils, obtained in accordance with Section 10.

Section 12.—Renumber the present Section 12, together with the heading "Inspection," to read Section 16.

Table II.—Revise the present heading of column 6 to read "Nominal Area, sq mils." Revise the present heading of column 7 to read "Nominal Area Working Value, sq mils." Revise the tabular data in column 7 by changing the factor "10^4" to read "10^3," simultaneously moving the decimal point (.) in each of the numbers in that column *one place to the right.*

Note 7.—Revise to read as follows:

NOTE 7.—Table II gives data on the cross-sectional area of square wire in sizes 0.0508 to 0.4600 in., inclusive, allowance having been made for reduction of the theoretical area of a perfect square wire due to the rounding of its four corners as shown in Table I of these specifications. These areas are for the nominal dimensions shown in column 1 of Table II and do not take into account the variations in the dimensions of an actual wire as permitted by the tolerances given in these specifications. The significance of these nominal working area values should not extend beyond the significance of the values in column 1 and it is for this reason that the nominal working area values have been rounded off as shown in column 7. Attention is also called to the fact that the values obtained by the equations of Section 12(*b*) are for wire of nominal dimensions and do not take into account probable increase or decrease of the values due to the variations of the dimensions of an actual wire within the limits of the specified tolerances. "Square mils" is a term used to express cross-sectional area of square and rectangular sections. A square mil is the area of a square, one mil on each side. Thus, if dimensions of a rectangular section are expressed in mils, the area of that section in square mils is the product of thickness times width. The relationship between circular mils and square mils is that of a circle to its circumscribing square. Thus, one circular mil = 0.7854 square mil.

Note 11.—Delete the present Explanatory Note 11 in its entirety. (It has been incorporated in revised Note 7.)

Note 12.—Renumber the present Explanatory Note 12 to read Note 11.

Standard Specifications for Hard-Drawn Copper Alloy Wires for Electrical Conductors (B 105 – 53):[3]

Section 4(a).—Revise the minimum copper content requirement from "94.00" to read "89.00" per cent. Insert a new element, to read "Zinc, max, per cent . . . 10.50."

Note 1.—In the list of chemical compositions, insert a new alloy type for alloy 30, below and in addition to the present "Copper, Tin," to read "Copper, Zinc, Tin."

Standard Specifications for Figure-9 Deep-Section Grooved and Figure-8 Copper Trolley Wire for Industrial Haulage (B 116 – 52):[4]

Incorporate into the specifications the proposed revisions listed under Editorial Note. Revise the proposed new Section 6(*e*) to include after the second sentence of the second paragraph a new sentence reading: "Samples shall be clean and ends free from burrs."

Fig. 1.—In the tabular data for Area, cir mils (Note 6), editorially change the present value "133,200" to read "133,100." (This is a typographical error inadvertently carried over from the 1949 revision.)

Standard Specifications for Concentric-Lay-Stranded Aluminum Conductors, Hard-Drawn and Three-Quarter Hard-Drawn (B 231 – 54):[2]

Section 4.—Revise the second sentence to read: "In other conductors, electric butt-welds or cold pressure-welds may be made in the finished wires composing conductors, but such joints shall be not closer than prescribed in Table I."

Standard Specifications for Rolled Aluminum Rods (EC Grade) for Electrical Purposes (B 233 – 54):[2]

Section 9.—Revise to read: "Joints in the rod, if agreed upon by the purchaser (Section 3(*a*)), shall be made by electric butt-welding or by cold pressure-welding."

REAPPROVAL OF STANDARD

The committee recommends that the Standard Method of Test for Resistivity of Electrical Conductor Materials (**B 193 – 49**)[4] be reapproved as standard.

The recommendations in this report have been submitted to letter ballot of the committee, the results of which will be reported at the Annual Meeting.[5]

ACTIVITIES OF SUBCOMMITTEES

Subcommittee I on Editorial and Records (A. A. Jones, chairman) continued its editorial review of specifications and coordinated the various subcommittee recommendations regarding revisions of the various specifications. During the year, it conducted a survey of its membership regarding the use of singular *versus* plural for unit designation in tabular headings. Because of divided opinion, action was taken in Committee B-1 to record the committee as favoring the use of tabular heading unit designations abbreviated in accordance with ASA Standard Z10.1-1941.

Subcommittee II on Methods of Test and Sampling Procedures (R. H. Lloyd, chairman) was inactive during part of the year awaiting appointment of a new chairman. It is developing statistical sampling procedures for tinned- and alloy-coated copper, and is continuing its assignments to formulate a standard method of calculating lay factor (weight increment) for inclusion in Method B 263 and to develop an alternate method (to the bell method) of measuring elongation in 60-in. gage length (for HD and MHD wire).

Subcommittee IV on Conductors of Copper and Copper Alloys (B. J. Sirois, chairman) completed preparation of the proposed Tentative Specifications for Silver-Coated Soft or Annealed Copper Wire, and revision of Specifications B 8, B 9, B 47, B 48, B 105, and B 116.

Task groups are collecting and analyzing test data on commercial production of soft, square, and rectangular copper wire to be used as a basis for establishing acceptance limits when tested in accordance with the Tentative Method of Test for Stiffness of Bare Soft Square and Rectangular Copper Wire for Magnet Wire Fabrication (ASTM Designation: B 279); cooperating with the U. S. Army Signal Corps Engineering Laboratories in the study of grey-tin transformation; and cooperating with the National Bureau of Standards in the proposed revision of NBS *Circular No. 31*, Copper Wire Tables.

Subcommittee VII on Conductors of Light Metals (P. V. Faragher, chairman) completed revisions of Specifications B 230, B 231, B 232, and B 233 incorporating recognition of cold pressure-welding and some additional sizes of ACSR.

Task groups are considering preparation of proposed specifications for annealed or one-quarter hard aluminum wire for telephone applications and for aluminum wire to be used in magnet wire. Consideration was given to revising the aluminum wire diameter tolerances to conform to the closer tolerances required for copper wire; it was concluded that the present aluminum wire diameter tolerances are adequate.

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[5] The letter ballot vote on these recommendations was favorable; the results of the vote are on record at ASTM Headquarters.

This report has been submitted to letter ballot of the committee, which consists of 79 members; 57½ members returned their ballots, all of whom have voted affirmatively.

Respectfully submitted on behalf of the committee,

D. HALLORAN,
Chairman.

A. A. JONES,
Secretary.

REPORT OF COMMITTEE B-2

ON

NON-FERROUS METALS AND ALLOYS*

Committee B-2 on Non-Ferrous Metals and Alloys met on June 15, 1954, in Chicago, Ill. During the past year the work of the committee has been handled by correspondence. A meeting of the Advisory Committee was held on December 17, 1954, in New York City.

NEW TENTATIVE

The committee recommends for publication as tentative the Proposed Tentative Specifications for Titanium Sponge, as appended hereto.[1]

REVISION OF TENTATIVE

The committee recommends that the Tentative Specifications for Fire-Refined Casting Copper (**B 72 - 47 T**)[2] be revised as appended hereto.[3]

REVISION OF STANDARD, IMMEDIATE ADOPTION

The committee recommends for immediate adoption the following revisions of Standard Specifications for Pig Lead (**B 29 - 49**)[4] and accordingly requests the necessary nine-tenths affirmative vote at the Annual Meeting in order that these revisions may be referred to letter ballot of the Society:

Section 2.—Revise to read as follows:

2. The following types of lead are covered:
Corroding lead,
Chemical lead,
Acid-copper lead, and
Common desilverized lead.

Section 6(a).—Add a note at the end of Paragraph (*a*) to read: "If the method of sampling specified in this section is not applicable to sampling large, heavy pigs differing in shape and size from those shown in Fig. 1, the manufacturer and the purchaser should mutually agree as to the method to be followed in sampling such large pigs."

Table I.—Revise to read as shown in the accompanying Table I.

Figure 3.—Delete Fig. 3 from the specifications.

WITHDRAWAL OF TENTATIVES

Since there is no further need for specifications for titanium ingot and for iodide titanium, the committee is recommending withdrawal of the Tentative Specifications for Titanium Ingot (**B 264 - 52 T**)[2] and for Iodide Titanium (**B 266 - 52 T**).[2]

REAPPROVAL OF STANDARDS

The committee recommends for reapproval the following 13 standards:

Standard Specifications for:

Lake Copper Wire Bars, Cakes, Slabs, Billets, Ingots, and Ingot Bars (**B 4 - 42**),
Electrolytic Copper Wire Bars, Cakes, Slabs, Billets, Ingots, and Ingot Bars (**B 5 - 43**),
Slab Zinc (Spelter) (**B 6 - 49**),

*** Presented at the Fifty-eighth Annual Meeting of the Society, June 26-July 1, 1955.**

[1] The new tentative appears in the 1955 Book of ASTM Standards, Part 2.

[2] 1952 Book of ASTM Standards, Part 2.

[3] The revised tentative appears in the 1955 Book of ASTM Standards, Part 2.

[4] The revised standard appears in the 1955 Book of ASTM Standards, Part 2.

White Metal Bearing Alloys (Known Commercially as "Babbitt Metal") (**B 23 - 49**),
Soft Solder Metal (**B 32 - 49**),
Nickel (**B 39 - 22**),
Rolled Zinc (**B 69 - 39**),
Lead-Coated Copper Sheets (**B 101 - 40**),
Electrolytic Cathode Copper (**B 115 - 43**),
Oxygen-Free Electrolytic Copper Wire Bars, Billets, and Cakes (**B 170 - 47**),
Fire-Refined Copper for Wrought Products and Alloys (**B 216 - 49**),
Metallic Antimony (**B 237 - 52**), and

Classification of:

Coppers (**B 224 - 52**).

Nickel-Copper Alloy Seamless Pipe and Tubing (**B 165 - 49 T**),
Nickel-Chromium-Iron Alloy Rods andars B (**B 166 - 49 T**),
Nickel-Chromium-Iron Alloy Seamless Pipe and Tubing (**B 167 - 49 T**),
Nickel-Chromium-Iron Alloy Plate, Sheet, and Strip (**B 168 - 49 T**),
Titanium Strip, Sheet, Plate, Bar, Tube, Rod, and Wire (**B 265 - 52 T**), and
Rosin Flux Cored Solder (**B 284 - 53 T**).

The recommendations in this report have been submitted to letter ballot of the committee, the results of which will be reported at the Annual Meeting.[5]

TABLE I.—CHEMICAL REQUIREMENTS.
(Revision of Table I, B 29.)

	Corroding Lead[a]	Chemical Lead[a]	Acid-Copper Lead[a]	Common Desilverized Lead[a]
Silver, max, per cent	0.0015	0.020	0.002	0.002
Silver, min, per cent	...	0.002	...	...
Copper, max, per cent	0.0015	0.080	0.080	0.0025
Copper, min, per cent	...	0.040	0.040	...
Silver and copper together, max, per cent	0.0025	...	0.040	...
Arsenic, antimony, and tin together, max, per cent	0.002	0.002	0.002	0.005
Zinc, max, per cent	0.001	0.001	0.001	0.002
Iron, max, per cent	0.002	0.002	0.002	0.002
Bismuth, max, per cent	0.050	0.005	0.025	0.150
Lead (by difference), min, per cent	99.94	99.90	99.90	99.85

[a] EXPLANATORY NOTE:

Corroding lead is a designation that has been used in the trade for many years to describe lead which has been refined to a high degree of purity.

Chemical lead has been used in the trade to describe the undesilverized lead produced from Southeastern Missouri ores.

Acid-Copper Lead is made by adding copper to fully refined lead.

Common desilverized lead is a designation used to describe fully refined desilverized lead.

TENTATIVES CONTINUED WITHOUT REVISION

The committee recommends that the following 12 specifications be continued as tentative without change:

Tentative Specifications for:

Nickel-Copper Alloy Plate, Sheet, and Strip (**B 127 - 49 T**),
Nickel Rods and Bars (**B 160 - 49 T**),
Nickel Seamless Pipe and Tubing (**B 161 - 49 T**),
Nickel Plate, Sheet, and Strip (**B 162 - 49 T**),
Seamless Nickel and High Nickel Alloy Condenser, Evaporator and Heat-Exchanger Tubes (**B 163 - 49 T**),
Nickel-Copper Alloy Rods and Bars (**B 164 - 49 T**),

ACTIVITIES OF SUBCOMMITTEES

Subcommittee I on Refined Copper (William E. Milligan, chairman).—A task group organized specifically for the purpose completed the revision of the Tentative Specification for Fire-Refined Casting Copper (B 72 - 47 T). The subcommittee has requested that the representative of Committee B-2 on the Non-Ferrous Metals Coordinating Committee take favorable action on a proposed revision of the definition of copper in the Standard Classification of Coppers (B 224 - 52), which classification is under joint jurisdiction of Committees B-1, B-2, and B-5.

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[5] The letter ballot vote on these recommendations was favorable; the results of the vote are on record at ASTM Headquarters.

Subcommittee II on Refined Lead, Tin, Antimony, and Bismuth (Sidney Rolle, chairman) prepared the revision of the Standard Specifications for Pig Lead (B 29 - 55). Through a task group the subcommittee is considering a possible specification for lead of secondary origin. The work on the preparation of a classification of tin continues, and it is expected that the task group in charge will be in a position to report during the Annual Meeting.

Subcommittee III on White Metals and Alloys (G. H. Clamer, chairman) is sponsoring a symposium on solder and soldering which is expected to be held during 1956.

Subcommittee IV on Refined Zinc and Wrought Zinc (E. H. Bunce, chairman).—In its consideration of the Standard Specifications for Slab Zinc (Spelter) (B 6 - 49), the subcommittee has requested Committees E-2 on Emission Spectroscopy and E-3 on Chemical Analysis of Metals to indicate a simple method for the determination of aluminum in zinc in the range of 0.001 per cent or less.

Subcommittee VI on Coated Metals (F. L. Scovill, Jr., chairman).—Through a task group, the study continues of methods of test for continuity of coating of lead-coated copper sheets in Standard Specifications for Lead-Coated Copper Sheets (B 101 - 40).

Subcommittee VII on Refined Nickel and Cobalt, High-Nickel Alloys, and High-Cobalt Alloys Cast and Wrought (O. B. J. Fraser, chairman; E. R. Patton, secretary) continues to review the specifications under its jurisdiction and expects shortly to submit recommendations with respect to a number of these specifications, together with proposed specifications for nickel-molybdenum-chromium alloy and nickel-molybdenum alloy in cast and fabricated forms.

Subcommittee VIII on Miscellaneous Refined Metals and Alloys (E. E. Schumacher, chairman).—The task group on titanium prepared the specification for titanium sponge referred to previously in the report for publication as tentative. The task group has recommended the withdrawal of Tentative Specifications for Titanium Ingot (B 264 - 52 T) and for Iodide Titanium (B 266 - 52 T).

This report has been submitted to letter ballot of the committee, which consists of 134 members; 84 members returned their ballots, all of whom have voted affirmatively.

Respectfully submitted on behalf of the committee,

BRUCE W. GONSER
Chairman.

G. HOWARD LEFEVRE,
Secretary.

REPORT OF COMMITTEE B-3
ON
CORROSION OF NON-FERROUS METALS AND ALLOYS*

Committee B-3 on Corrosion of Non-Ferrous Metals and Alloys held two meetings during the past year: in Chicago, Ill., on June 16, 1954, and in Cincinnati, Ohio, on February 2, 1955.

The committee consists of 95 members, of whom 82 are voting members; 27 are classified as consumers, 37 as producers, and 18 as general interest members.

TENTATIVES CONTINUED WITHOUT REVISION

The committee recommends that the following test methods be continued as tentative without change:

Tentative Method of:

Total Immersion Corrosion Test of Non-Ferrous Metals (**B 185 - 43 T**),
Alternate Immersion Corrosion Test of Non-Ferrous Metals (**B 192 - 44 T**),
Salt Spray (Fog) Testing (**B 117 - 54 T**), and
Acetic Acid-Salt Spray (Fog) Testing (**B 287 - 54 T**).

ACTIVITIES OF SUBCOMMITTEES

Subcommittee V on Statistical Analysis and Planning of Corrosion Testing (P. S. Olmstead, chairman) has assisted task groups of Subcommittees VI and VIII in evaluating data from their atmospheric exposure tests.

Subcommittee VI on Atmospheric Corrosion (W. H. Finkeldey, chairman).—A task group has obtained data on weight loss and tensile strength loss on specimens of twenty-four metals exposed to several outdoor atmospheres over a period of 20 years. The data form the basis for a Symposium on Atmospheric Corrosion of Non-Ferrous Metals at the 1955 Annual Meeting and are published with the papers of that symposium.[1]

Subcommittee VII on Weather (C. P. Larrabee, chairman).—A task group of the subcommittee has continued its program of calibrating the corrosiveness of the atmosphere at various test sites. Preliminary results of this program, which will terminate in 1956, indicate that the weight losses resulting from one year's exposure of panels of zinc and steel will give a good idea of the relative corrosivity of test sites. Other data have shown that the relative corrosivity factor for marine and rural atmospheres will vary with metal used to compare them. For example, copper and iron may give definitely different results.

Subcommittee VIII on Galvanic and Electrolytic Corrosion (G. V. Kingsley, chairman) has continued its program of tests on magnesium coupled to other metals exposed at several ASTM test sites. The weight loss data on the first set of disk couples has been evaluated, and a paper has been prepared by H. O. Teeple for presentation at the 1955 Symposium on Atmospheric Corrosion.

The task group working on the third part of the program—the so-called plate-type couples—has concluded pilot scale corrosion tests which indicate the type of corrosion test specimen that will be most suitable. Commitments for some of the test materials have been obtained.

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* Presented at the Fifty-eighth Annual Meeting of the Society, June 26–July 1, 1955.

[1] Issued as separate publication *ASTM STP No. 175.*

Information was received from the Pennsylvania Railroad Co. that roof repairs would necessitate the removal of the stainless steel couples from the roof of the Storehouse Building, Juniata Shops, Altoona, Pa. Although an alternate site in the same general location is available, it has been the decision to bring in all of the Altoona specimens which will result in a total exposure time of 14 yr.

This report has been submitted to letter ballot of the committee, which consists of 82 voting members; 65 members returned their ballots, all of whom have voted affirmatively.

Respectfully submitted on behalf of the committee,

K. G. COMPTON,
Chairman.

A. W. TRACY,
Secretary.

REPORT OF COMMITTEE B-4

ON

METALLIC MATERIALS FOR ELECTRICAL HEATING, ELECTRICAL RESISTANCE, AND ELECTRONIC APPLICATIONS*

Committee B-4 on Metallic Materials for Electrical Heating, Electrical Resistance, and Electronic Applications held two meetings during the past year: the fall meeting in Washington, D. C., on September 23 and 24, 1954, and the winter meeting in New York City on January 27 and 28, 1955. Subcommittees I, V, and IX met in Pittsburgh, Pa., on June 28, 1954, and Subcommittee X met in Atlantic City, N. J., on June 25, 1954.

The present membership of Committee B-4 totals 63 members, of whom 21 are classified as producers, 34 as consumers, and 8 as general interest members.

At the Washington meeting, Robert G. Breckenridge of the National Bureau of Standards gave an enlightening talk on "Intermetallic Semiconductors."

COMMITTEE REORGANIZATION

At the January meeting, Committee B-4 formally approved the separation of Subcommittee VIII on Materials for Radio Tubes and Incandescent Lamps from Committee B-4, in order to form a new ASTM Committee based on the activities of Subcommittee VIII. Two committees on reorganization were appointed, one for the new committee to be concerned with materials for electron tubes and semiconductor devices, and the other for the remaining subcommittees of Committee B-4 concerned with materials for electrical heating, electrical resistance, thermostats, and electrical contacts. The plan for reorganization is before the Board of Directors for approval.

RECOMMENDATIONS ACCEPTED BY THE ADMINISTRATIVE COMMITTEE ON STANDARDS

Subsequent to the 1954 Annual Meeting, Committee B-4 presented to the Society through the Administrative Committee on Standards the following recommendations:

Revision of Tentative Methods of:

Testing Sleeves and Tubing for Radio Tube Cathodes **(B 128 - 52 T),**

Test for Sublimation Characteristics of Metallic Materials by Electrical Resistance **(B 278 - 52 T),**

Revision of Tentative Recommended Practice for:

Cathode Melt Prove-In Testing **(B 238 - 49 T),** and

Revision and Reversion to Tentative of Standard Method of:

Test for Diameter by Weighing of Fine Wire Used in Electronic Devices and Lamps **(B 205 - 49).**

These recommendations were accepted by the Standards Committee on March 23, 1955. The revised methods and recommended practice will appear in the 1955 Book of ASTM Standards, Part 6.[1]

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* Presented at the Fifty-eighth Annual Meeting of the Society, June 26–July 1, 1955.

NEW TENTATIVE

The committee recommends for publication as tentative the Methods of Test for Interface Impedance Characteristics of Vacuum Tube Cathodes, as appended hereto.[1a]

ADOPTION OF TENTATIVE AS STANDARD WITHOUT REVISION

The committee recommends that the Tentative Method of Test for Hardness of Electrical Contact Materials (**B 277 - 52 T**)[2] be approved for reference to letter ballot of the Society for adoption as standard without change.

The recommendations in this report have been submitted to letter ballot of the committee, the results of which will be reported at the Annual Meeting.[3]

ACTIVITIES OF SUBCOMMITTEES

Subcommittee I on Electrical Heating Materials (C. W. Armstrong, chairman) is continuing its work on the revision of the Method of Test for Change of Resistance with Temperature of Metallic Materials for Electrical Heating (B 70 - 39). Three laboratories have contributed formal reports suggesting specific changes in the specification. After one more laboratory makes its report and after checking the standard alloys in the field according to the suggested changes, adoption of the revised specification is expected.

The revision of Method B 70 - 39 will introduce changes in the temperature-resistance relationship in the Standard Specification for Drawn or Rolled Alloy, 80 per cent Nickel, 20 per cent Chromium for Electrical-Heating Elements (B 82 - 52), and the Standard Specification for Drawn or Rolled Alloy, 60 per cent Nickel, 16 per cent Chromium, Balance Iron, for Electrical-Heating Elements (B 83 - 52).

Two proposed changes in the Tentative Specification on High-Resistivity, Low-Temperature Coefficient Wire (B 267 - 53 T) are being considered pending completion of data from one laboratory.

In reference to the proposal to include in the Standard Method of Life Test of the Electrical Materials for Electrical Heating (B 76 - 39) a method of test for iron-chromium-aluminum type alloys, three formal reports have been presented suggesting specific procedures.

Subcommittee V on Wrought and Cast Alloys for High-Temperature Use (E. Edmunds, chairman) and *Subcommittee IX on Methods of Test for Alloys in Controlled Atmospheres* (P. H. Brace, chairman) have been attempting to formulate a clear definition of "green rot" attack and to obtain specific examples of the phenomenon. Many failures continue to be classified as "green rot" which actually are unrelated and result in confusing the problem.

Subcommittee VII on Thermostat Metals (P. H. Brace, chairman) has recommended five minor changes in the Tentative Method of Testing Thermostat Metals (B 106 - 51 T). The revised method has been approved for reference to letter ballot. Likewise, a proposed Tentative Method of Test for Maximum Loading Stress at Temperature of Thermostat Metals, a revision of the Standard Method of Test of Modulus of Elasticity of Thermostat Metals (Cantilever Beam Method) (B 223 - 51 T), and the withdrawal of Test for Yield Stress of Thermostat

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[1] These tentatives now bear F designations since they are now under the jurisdiction of Committee F-1 on Materials for Electron Tubes, etc.

[1a] The new tentative appears in the 1955 Book of ASTM Standards, Part 6.

[2] 1952 Book of ASTM Standards, Part 2.

[3] The letter ballot vote on these recommendations was favorable; the results of the vote are on record at ASTM Headquarters.

Metals (B 191 - 50) have been approved for submittal to letter ballot.

Subcommittee VIII on Metallic Materials for Radio Tubes and Incandescent Lamps (S. A. Standing, chairman):

Section A on Cathode Materials has provided a proposed Tentative Specification for Interface Impedance Characteristics of Vacuum Tube Cathodes, referred to previously in this report.[1]

The section is continuing its work on the evaluation of vacuum-melted nickel.

Two methods for the vacuum fusion gas analysis of oxygen, nitrogen, and hydrogen in nickel have been approved but await editorial review and possible combination. A low-pressure combustion method for the determination of carbon in nickel is to be submitted to letter ballot.

A chemical method for the determination of aluminum in nickel, accepted by the chemical analysis task force, will be submitted to Committee E-3 for approval. Work is continuing on a method for the determination of magnesium. Cooperative tests with the spectrographic analysis task force in the analysis of a commercial melt of nickel are to be undertaken.

Work is continuing on a standard triode and a definition of cathode activity.

Revision of the Tentative Specification for Circular Cross-Section Nickel Alloy Cathode Sleeves for Electronic Devices (B 239 - 49 T) is nearing completion.

Section C on Wires is suggesting changes to be incorporated in the Tentative Specification on Molybdenum Wire (B 289) with early acceptance contemplated. Suggested changes in the Tentative Specification on Grid Lateral and Vertical Wires (B 290) will require further consideration before decisions can be reached.

Section F on Mica and Ceramics has circulated a list of micas to be obtained for evaluation. A standard report method and a program for each cooperating organization are being considered.

Section G on Clad and Plated Materials has distributed for consideration the seventh revision of a proposed Tentative Specification for Strip Material for Radio Tube and Incandescent Lamp Use. Round-robin tests conducted in accordance with the Method of Test for Temper of Strip and Sheet Metals for Electronic Devices (Springback Method) (B 155 - 50) were run using a number of springback testers and the results evaluated.

Subcommittee X on Contact Materials (J. D. Kleis, chairman) is continuing its work in the life test section on the surety of making a circuit test, and under physical properties thermal conductivity remains under consideration. Comments are being obtained from consumers on a proposed standardization of sizes for projection welding contacts. Round-robin tests on high-current contacts have been completed. A device has been adopted tentatively for the testing of microcontacts.

Essentially all work on the 1954 Supplement to the Bibliography and Abstracts on Electrical Contacts[4] has been completed except for the index and introduction.

The report has been submitted to letter ballot of the committee, which consists of 63 members; 44 members returned their ballot, of whom 36 have voted affirmatively and 0 negatively.

Respectfully submitted on behalf of the committee,

S. A. STANDING,
Chairman.

E. I. SHOBERT,
Vice-Chairman.
STANTON UMBREIT,
Secretary.

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[4] Issued as separate publication *ASTM STP No. 56-H.*

REPORT OF COMMITTEE B-5

ON

COPPER AND COPPER ALLOYS, CAST AND WROUGHT*

Committee B-5 on Copper and Copper Alloys, Cast and Wrought, held two meetings during the year: at Washington, D. C., on October 6, 1954, and at New York, N. Y., on January 20, 1955. At these two sessions the Executive Subcommittee and Subcommittees W-1, W-2, W-3, W-4 and G-1 also met; Subcommittee G-3 met at the January sessions.

During the year, 5 members were added to the Committee and there were 7 removals. At the present time the committee consists of 134 members of whom 108 are voting members; 50 are classified as producers, 39 as consumers, and 19 as general interest members.

Revisions in the Regulations Governing Committee B-5 were approved during the year, the revisions having been prepared by a task group of which L. H. Adam was chairman.

A paper entitled "A Mathematical Formula for the Calculation of the Tensile Strength of Copper-Silicon-Manganese-Iron Alloy" by G. H. Bohn of Linde Air Products Co. was presented at the January meeting of the committee and is appended hereto.[1]

A paper by G. R. Gohn entitled "A Hardness Conversion Table for Copper-Beryllium Alloy Strip" will be presented at the Annual Meeting. This paper presents data which resulted from the work of a special task group operating under Subcommittee W-1 and is appended hereto.[2]

RECOMMENDATIONS AFFECTING STANDARDS

The committee is submitting 2 new tentative specifications, revisions in 7 tentative specifications, revisions in 30 standards for immediate adoption, and the withdrawal of 1 standard. The standards and tentatives affected, together with the revisions recommended, are covered in detail in Appendix I.[3]

The recommendations in this report have been submitted to letter ballot of the committee, the results of which will be reported at the Annual Meeting.[4]

ACTIVITIES OF SUBCOMMITTEES

The following is the report of the several subcommittees during the year. The actions on standards are given in detail in the Appendix.

Subcommittee W-1 on Plate, Sheet, and Strip (A. E. Moredock, chairman) recommended that revisions be incorporated in Tentative Specifications B 122, B 248, and B 291. Revisions for immediate adoption were recommended in Standard Specifications B 11, B 19, B 36, B 96, B 97, B 100, B 103, B 121, B 129, B 130, B 131, B 152, B 169, B 171, and B 194.

A task group (V. P. Weaver, chairman) prepared the requirements for size limitations for Specification B 100. Task groups (G. C. Mutch and G. B. Smith, chairmen) prepared, respectively, requirements for 90-10 copper-nickel alloy, and for the number of tension tests in Specification B 171.

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* Presented at the Fifty-eighth Annual Meeting of the Society, June 26–July 1, 1955.

[1] See p. 199.

[2] See p. 230.

[3] See p. 193.

[4] The letter ballot vote on these recommendations was favorable; the results of the vote are on record at ASTM Headquarters.

Among the subjects being considered by the subcommittee are the revisions of basis of purchase sections, preparation of requirements for tin-coated copper, the revision of flatness tolerances for Specification B 171, and the addition of a hardness conversion table to Specification B 194.

Subcommittee W-2 on Rods, Bars, and Shapes (J. D. MacQueen, chairman) recommended that revisions be incorporated in Tentative Specification B 249. Revisions for immediate adoption were recommended in Standard Specifications B 12, B 98, B 124, and B 187. The subcommittee recommends a proposed new Tentative Specification for Tellurium Copper Rod[5] prepared by a task group (M. F. Groves, chairman) and also recommends that Specification B 283 be continued as tentative without revision.

A task group (M. J. Mianulli, chairman) prepared the revisions in Specification B 124. Another task group (M. D. Helfrick, chairman) prepared requirements for 10 per cent and 12 per cent nickel silver being incorporated in Specification B 151. Still another task group (G. H. Harnden, chairman) prepared the revisions in bend test requirements for Specification B 187.

Among the subjects being considered by the subcommittee are the revision of chemical requirements for rod of type OF copper, consideration of leaded nickel silvers of lower nickel content for Specification B 151, and in Specification B 139 the clarification of requirements for test specimens.

Subcommittee W-3 on Wire and Wire Rod (Sidney Metzger, chairman) recommended that revisions be incorporated in Tentative Specification B 250, and that Specification B 272 be continued as tentative without revision.

Among the subjects under consideration in the subcommittee are the revision of chemical requirements for alloy A and provisions for stress-relief annealing of alloy A spring wire in Specification B 159; in Specification B 206, the revision of chemical requirements for alloy C, and the development of requirements for 10 per cent nickel silver; and preparation of requirements for flat copper products with finished edges in sizes wider than provided for in Specification B 272.

Subcommittee W-4 on Pipe and Tube (G. C. Mutch, chairman) recommended that revisions be incorporated in Tentative Specifications B 251 and B 280. Revisions for immediate adoption were recommended in Standard Specifications B 13, B 42, B 43, B 68, B 75, B 88, B 111, B 135, and B 188. The subcommittee recommends a proposed new Tentative Specification for Threadless Copper Pipe[5] prepared by a task group (G. C. Mutch, chairman), and also recommends withdrawal of Standard Specification B 14.

One task group (V. P. Weaver, chairman) prepared tensile strength and yield strength requirements for the following specifications when used in the ASME Boiler and Pressure Vessel Code: B 13, B 42, B 43, B 75, and B 111. A task group (B. J. Sirois, chairman) prepared the revisions for finish requirements in Specification B 111. Another task group (M. F. W. Heberlein, chairman) investigated the advisability of withdrawing Specification B 14.

Among the subjects under consideration in the subcommittee are the review of temper requirements in Specification B 75 and requirements for Rockwell hardness in tube specifications; for

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[5] The new tentative appears in the 1955 Book of ASTM Standards, Part 2.

Specification B 111, the revision of requirements for the expanding test, the mercurous nitrate test, and the dimensional tolerances; revision of chemical requirements for type OF copper in Specification B 75; and preparation of a new specification for copper-silicon alloy pipe and tube.

Subcommittee F-1 on Castings, and Ingots for Remelting (G. H. Clamer, chairman; M. L. Steinbuch, secretary) recommended that Specifications B 52 and B 53 and Classification B 119 be continued as standard without revision.

Among the subjects under consideration in the subcommittee are the revision of chemical requirements in Specification B 198, the review of chemical compositions for the proper number of significant figures, and the assembling of data on properties of cast copper-base alloys.

Subcommittee G-1 on Methods of Test (G. R. Gohn, chairman; J. P. Guerard, secretary) recommended revisions for immediate adoption in Standard Method B 153. Standard Methods B 153 and B 154 are being recommended for approval as American Standard by the American Standards Association.

The subcommittee is preparing a series of revisions in the dimensional tolerance requirements as now set forth in the various wrought-product specifications, together with a recommended practice on dimensional measurements which will include, in the case of dispute or referee test, the choice of instrument for determining various dimensions. The subcommittee is also continuing its studies on the relation between the thickness of the test strip and the Rockwell hardness.

Subcommittee G-2 on Tolerances (J. E. McGraw, chairman), in cooperation with Subcommittee W-1, recommended for Specification B 248 an increase in the thickness range for width tolerances for slit metal and slit metal with rolled edges.

Subcommittee G-3 on Editorial and Publications (W. F. Roeser, chairman) recommended that a new edition of the special volume of ASTM Standards on Copper and Copper Alloys be issued in 1955 and that Tentative Definitions E 6 and Tentative Method E 10 be included. A proposed new Tentative Classification of Wrought Copper-Base Alloys recommended by the subcommittee will be published in the special volume as information.

In cooperation with Subcommittee F-1 and the "W" Subcommittees, the specifications under the jurisdiction of these subcommittees are being reviewed for editorial consistency.

This report has been submitted to letter ballot of the committee, which consists of 108 voting members; 93 members returned their ballots, of whom 90 have voted affirmatively and 0 negatively.

Respectfully submitted on behalf of the committee,

G. H. HARNDEN,
Chairman.

V. P. WEAVER,
Secretary.

APPENDIX I

RECOMMENDATIONS AFFECTING STANDARDS FOR COPPER AND COPPER ALLOYS, CAST AND WROUGHT

In this Appendix are given the recommendations affecting certain standards covering copper and copper alloys which are referred to earlier in this report. The standards appear in their present form in the 1952 Book of ASTM Standards, Part 2, or in the 1953 and 1954 Supplements to the Book of ASTM Standards, Part 2.

NEW TENTATIVES

The committee recommends the following two new specifications for publication as tentative:[1]

Tentative Specification for Tellurium Copper Rod, and
Tentative Specification for Threadless Copper Pipe.

REVISIONS OF TENTATIVES

The committee recommends that the following seven tentative specifications be revised as indicated below and continued as tentative.

Tentative Specification for Copper-Nickel-Zinc Alloy (Nickel Silver) and Copper-Nickel Alloy Plate, Sheet, Strip, and Rolled Bar (B 122 – 54 T):

Section 7.—Add at the end of the section a sentence to read: "Tension test specimens shall be taken so that the longitudinal axis of such specimens is parallel to the direction of rolling."

Tentative Specification for General Requirements for Wrought Copper and Copper-Alloy Plate, Sheet, Strip, and Rolled Bar (B 248 – 53 T):

Section 8.—Revise Paragraph (*a*) to read: "**General.**—For the purpose of determining conformance with the dimensional requirements given in this specification, any measured value outside the specified limiting values for any dimension may be cause for rejection."

Table IV.—In the fifth column heading, increase the maximum thickness limit "0.375" to a new value of "0.500."

Tentative Specification for General Requirements for Wrought Copper and Copper-Alloy Rod, Bar, and Shapes (B 249 – 53 T):

Delete all requirements that are applicable only to Specification B 124.

Section 8.—Revise as indicated above for Section 8 in Specification B 248.

Tentative Specification for General Requirements for Wrought Copper and Copper-Alloy Wire (B 250 – 52 T):

Section 8.—Revise as indicated above for Section 8 in Specification B 248.

Tentative Specification for General Requirements for Wrought Seamless Copper and Copper-Alloy Pipe and Tube (B 251 – 54 T):

Delete all requirements that are applicable only to Specification B 188.

Section 8.—In Paragraph (*a*) revise Item 2 to read as indicated above for Section 8 in Specification B 248, omitting the boldface heading "General."

Tentative Specification for Seamless Copper Tube for Refrigeration Field Service (B 280 – 53 T):

Section 8.—Add at the end of the section a sentence to read: "The expanded tube shall show no cracking or rupture visible to the unaided eye."

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[1] The new tentatives appear in the 1955 Book of ASTM Standards, Part 2.

Section 17.—Following Paragraph (*b*) add a note to read:

NOTE.—For the purpose of determining conformance with the dimensional requirements given in this specification, any measured value outside the specified limiting values for any dimension may be cause for rejection.

Tentative Specification for Copper-Zinc-Manganese Alloy (Manganese Brass) Sheet and Strip (B 291 – 54 T):

Section 8.—Revise as indicated above for Section 7 in Specification B 122.

Section 14.—Revise as indicated above for Section 8 in Specification B 248.

REVISION OF STANDARDS, IMMEDIATE ADOPTION

The committee recommends for immediate adoption revisions in 30 specifications as indicated below and accordingly asks for a nine-tenths affirmative vote at the Annual Meeting in order that these modifications may be recommended for letter ballot of the Society.

Standard Specification for Copper Plates for Locomotive Fire Boxes (B 11 – 54):

Section 8.—Revise the first sentence to read: "Tension and bend test specimens shall be taken so that the longitudinal axis of the specimens is parallel to the direction of rolling, and from the finished rolled material."

Standard Specification for Copper Rods for Locomotive Staybolts (B 12 – 54):

Section 12.—Revise the note to read:

NOTE.—For the purpose of determining conformance with the dimensional requirements given in this specification, any measured value outside the specified limiting values for any dimension may be cause for rejection.

Standard Specification for Seamless Copper Boiler Tubes (B 13 – 49):

Section 6.—Add at the end of section a note to read:

NOTE.—Material specified to meet requirements of the ASME Boiler and Pressure Vessel Code shall have in the annealed condition a minimum tensile strength of 30,000 psi and a minimum yield strength of 9000 psi at 0.5 per cent extension under load. The tension test shall be required only when definitely specified in the purchase order. The tensile properties shall, in case of disagreement, be determined in accordance with the Methods of Tension Testing of Metallic Materials (ASTM Designation: E 8).

Section 16.—Revise the note as indicated above for Section 12 in Specification B 12.

Standard Specification for Cartridge Brass Sheet, Strip, Plate, Bar, and Disks (B 19 – 54):

Sections 9, 11(*a*)*, and 11*(*b*).—Revise as indicated above for Section 7 in Specification B 122.

Section 15.—Revise Note 2 to read as indicated above for Section 12 in Specification B 12.

Standard Specification for Brass Plate, Sheet, Strip, and Rolled Bar (B 36 – 52):

Section 7.—Revise as indicated above for Section 7 in Specification B 122.

Standard Specification for Seamless Copper Pipe, Standard Sizes (B 42 – 54):

Section 5.—In Paragraph (*a*) revise "hard-drawn condition" to read "drawn temper" and following Paragraph (*a*) add a note to read:

NOTE.—Material specified to meet requirements of the ASME Boiler and Pressure Vessel Code shall have tensile properties as follows:

Temper	Tensile Strength, min, psi	Yield Strength, min, psi[a]
Annealed	30 000	9 000
Drawn	36 000	30 000

[a] At 0.5 per cent extension under load.

The tension test shall be required only when definitely specified in the purchase order.

Section 6(*a*).—At the end of the paragraph add a sentence to read: "The expanded tube shall show no cracking or rupture visible to the unaided eye."

Section 9(*b*).—In the last sentence

revise "hard-drawn condition" to read "drawn temper."

Standard Specification for Seamless Red Brass Pipe, Standard Sizes (B 43 - 54):

Section 5.—In the last sentence revise "hard-drawn condition" to read "drawn temper." At the end of the section add a note to read:

NOTE.—Material specified to meet requirements of the ASME Boiler and Pressure Vessel Code shall have in the annealed condition a minimum tensile strength of 40,000 psi and a minimum yield strength of 12,000 psi at 0.5 per cent extension under load. The tension test shall be required only when definitely specified in the purchase order.

Section 6(a).—Revise as indicated above for Section 6(*a*) in Specification B 42.

Standard Specification for Seamless Copper Tube, Bright Annealed (B 68 - 54):

Section 7(a).—Revise as indicated above for Section 6(*a*) in Specification B 42.

Standard Specification for Seamless Copper Tube (B 75 - 54):

Section 6(a).—Following Paragraph (*a*) add a note to read:

NOTE.—Material specified to meet requirements of the ASME Boiler and Pressure Vessel Code shall have physical properties as follows:

Temper	Tensile Strength, psi	Yield Strength, min, psi[a]
Annealed	30 000 min	9 000
Light-drawn	36 000 to 47 000	30 000
Hard-drawn	45 000 min	40 000

[a] At 0.5 per cent extension under load.

The tension test shall be required only when definitely specified in the purchase order.

Section 7(a).—Revise as indicated above for Section 6(*a*) in Specification B 42.

Standard Specification for Seamless Copper Water Tube (B 88 - 54):

Section 9(a).—Revise as indicated above for Section 6(*a*) in Specification B 42.

Standard Specification for Copper-Silicon Alloy Plate and Sheet for Pressure Vessels (B 96 - 54):

Table I.—For "Alloy A" revise the silicon range "2.8 to 3.6" to read "2.8 to 3.8 per cent."

Section 6.—Revise as indicated above for Section 7 in Specification B 122.

Section 10.—Revise the note as indicated above for Section 12 in Specification B 12.

Table III.—Under "alloy A" add alloy No. A-8 with chemical composition limits as follows:

Silicon, per cent	3.15 to 3.8
Iron, max, per cent	0.50
Manganese, per cent	0.20 to 0.95
Lead, max, per cent	0.05
Aluminum, max, per cent	0.01
Copper plus elements with specific limits, min, per cent	99.5

Standard Specification for Copper-Silicon Alloy Plate, Sheet, Strip, and Rolled Bar for General Purposes (B 97 - 54):

Table I, Section 5, and Table III.—Revise as indicated above for Table I, Section 6, and Table III, respectively, in Specification B 96.

Standard Specification for Copper-Silicon Alloy Rod, Bar, and Shapes (B 98 - 54):

Tables I and III.—Revise as indicated above for Tables I and III, respectively, in Specification B 96.

Standard Specification for Rolled Copper-Alloy Bearing and Expansion Plates and Sheets for Bridge and Other Structural Uses (B 100 - 54):

Section 6.—Revise as indicated above for Section 7 in Specification B 122.

Also add a new Paragraph (*a*), designating the present section as Paragraph (*b*), to read as follows:

(*a*) Under this specification, the maximum plate size shall be 30 in. wide by 36 in. long by 1¼ in. thick. The physical properties of material over 18 in. wide and over ¾ in. thick shall be subject to agreement between the manufacturer and the purchaser at the time of order.

Section 9.—Revise the note as indicated above for Section 12 in Specification B 12.

Standard Specification for Phosphor Bronze Plate, Sheet, Strip, and Rolled Bar (B 103 - 51):

Section 7.—Revise as indicated above for Section 7 in Specification B 122.

Standard Specification for Copper and Copper-Alloy Seamless Condenser Tubes and Ferrule Stock (B 111 - 54):

Throughout the specification change "alloy" to read "material."

Section 1.—In the first sentence revise "various copper alloys" to read "copper and various copper alloys."

Section 4.—At the end of the section add a note to read:

NOTE.—Material specified to meet requirements of the ASME Boiler and Pressure Vessel Code shall have tensile properties as prescribed in Table II. The tension test shall be required only when definitely specified in the purchase order.

Section 8(a).—In the first sentence delete "without showing signs of cracking or rupture." Insert a new second sentence to read: "The expanded tube shall show no cracking or rupture visible to the unaided eye."

Section 16.—Revise the note to read as indicated above for Section 12 in Specification B 12.

Section 18.—Revise to read: "Annealed-temper tubes shall be clean and smooth but may have a superficial, dull iridescent film on both the inside and the outside surface. Drawn-temper tubes shall be clean and smooth, but may have a superficial film of drawing lubricant on the surfaces."

Appendix.—As an Appendix add a new Table II to read as shown in the accompanying Table I.

TABLE I.—TENSILE REQUIREMENTS.[a]
(New Table II, B 111.)

Alloy	Temper	Tensile Strength, min, psi	Yield Strength, min, psi[b]
Muntz metal	annealed	50 000	20 000
Admiralty metal	annealed	45 000	15 000
Red brass	annealed	40 000	12 000
Aluminum brass	annealed	50 000	18 000
Aluminum bronze	annealed	50 000	19 000
70-30 copper-nickel alloy	annealed	52 000	18 000
80-20 copper-nickel alloy	annealed	45 000	16 000
90-10 copper-nickel alloy	annealed	40 000	15 000
Copper	light-drawn	36 000	30 000
	hard-drawn	45 000	40 000
Arsenical copper	light-drawn	36 000	30 000
	hard-drawn	45 000	40 000

[a] When so specified, two tubes shall be selected from each lot and subjected to the tension test which shall, in case of disagreement, be made in accordance with the Methods of Tension Testing of Metallic Materials (ASTM Designation: E 8), 1954 Supplement to Book of ASTM Standards, Part 2.

[b] At 0.5 per cent extension under load.

Standard Specification for Leaded Brass Plate, Sheet, Strip, and Rolled Bar (B 121 - 52):

Section 7.—Revise as indicated above for Section 7 in Specification B 122.

Standard Specification for Copper and Copper-Base Alloy Forging Rod, Bar, and Shapes (B 124 - 54):

The proposed revisions in this specification comprise deletion of reference to Specification B 249 in Sections 2 and 5, and the inclusion of all the requirements of B 249 that are applicable to this specification; also, deletion of alloys Nos. 5, 6, 8, 9, and 10; the addition of names for the remaining alloys; the addition of alloys Nos. 13 and 14; new copper limits of 58.0 to 61.0 for alloy No. 2; slight revision of Section 1; the addition of a straightness tolerance; and in Table III, the addition of densities, forgeability ratings, and the replacement of tensile properties by reference to those in Specification B 283. The revised specification is appended hereto.[2]

Standard Specification for Cartridge Brass Cartridge Case Cups (B 129 – 51):

Section 9.—Revise the note as indicated above for Section 12 in Specification B 12.

Standard Specification for Commercial Bronze Strip (B 130 – 54):

Sections 9 and 11.—Revise both sections as indicated above for Section 7 in Specification B 122.

Section 15, Note 2.—Revise to read as indicated above for Section 12 in Specification B 12.

Standard Specification for Commercial Bronze Bullet Jacket Cups (B 131 – 54):

Section 10.—Revise as indicated above for Section 12 in Specification B 12.

Standard Specification for Seamless Brass Tube (B 135 – 54):

Section 9(a).—Add a sentence to read: "The expanded tube shall show no cracking or rupture visible to the unaided eye."

Standard Specification for Copper-Nickel-Zinc Alloy (Nickel Silver) Rod and Bar (B 151 – 52):

Section 1.—Add to the table alloys D and E for general use, with nominal compositions as follows:

	Alloy D	Alloy E
Copper, per cent	65	65
Nickel, per cent	12	10
Zinc, per cent	23	25

Table I.—Add alloys D and E with chemical requirements as follows:

	Alloy D	Alloy E
Copper, per cent	63.5 to 66.5	63.5 to 66.5
Nickel, per cent	11.0 to 13.0	9.0 to 11.0
Lead, max, per cent	0.05	0.05
Iron, max, per cent	0.25	0.25
Manganese, max, per cent	0.50	0.50
Zinc, per cent	remainder	remainder

Table II.—In the present column heading referring to alloys B and B-1 add reference to alloys D and E.

Table III.—For the first column, revise the first two lines to read "All alloys" and in the third line add "D and E."

Standard Specification for Copper Sheet, Strip, Plate, and Rolled Bar (B 152 – 54):

Section 8.—Revise as indicated above for Section 7 in Specification B 122.

Standard Method of Test for Expansion (Pin Test) of Copper and Copper-Alloy Tubing (B 153 – 47):

Section 4(b).—Add a sentence to read: "The expanded tube shall be examined with the unaided eye (Note) to determine conformance with the product specification." Following Paragraph (*b*) add a note to read:

NOTE.—The term "unaided eye," as used herein, permits the use of corrective spectacles necessary to obtain normal vision.

Section 4(c).—After the words "hand hammering" insert "or by manually or mechanically pressing."

Standard Specification for Aluminum Bronze Plate, Sheet, Strip, and Rolled Bar (B 169 – 52):

Section 5.—Revise to read: "5. The material shall conform to the requirements as to tensile properties prescribed in Table II. Tension test specimens shall be taken so that the longitudinal axis of such specimens is parallel to the direction of rolling."

Table II.—Add a footnote "*a*" to the

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[2] The revised specification appears in the 1955 Book of ASTM Standards, Part 2.

column headed "Yield Strength" to read: "[a] The yield strength shall be determined as the stress producing an elongation of 0.5 per cent under load, that is, 0.01 in. in a gage length of 2 in."

Standard Specification for Copper-Alloy Condenser Tube Plates (B 171 – 54):

Section 1.—Revise "six" to read "seven."

Table I.—After column "Copper-Nickel Alloy" add a new column to read "90-10 Copper-Nickel Alloy" with the chemical requirements to correspond with those given for the same alloy in Table I of Specification B 111. Revise the column heading "Copper-Nickel Alloy" to read "70-30 Copper-Nickel Alloy."

Table II.—After "Copper-Nickel alloy" add "90-10 Copper-Nickel alloy" with tensile requirements for thickness 2.5 in. and under as follows:

Tensile strength, min, psi	40 000
Yield strength, min, psi	15 000
Elongation in 2 in., min, per cent	30

Revise the alloy designation "Copper-Nickel alloy" to read "70-30 Copper-Nickel alloy."

New Section.—After Section 8, add a new Section 9, renumbering subsequent sections accordingly, to read as follows:

> 9. *Number of Tests.*—One tension test shall be made for each 5000 lb or fraction thereof or for each single plate weighing in excess of this amount.

Section 9.—Revise the note as indicated above for Section 12 in Specification B 12.

Standard Specification for Copper Bus Bar, Rod, and Shapes (B 187 – 54):

Section 5(b) and (c).—In Paragraph (*b*) add a title "*Bar Flatwise and Rod Bend Test.*—"

In Paragraph (*c*) replace the words "The material" with "An unmachined specimen of bar material."

Section 8(c).—Revise the first sentence to read: "When a specimen for the bar flatwise and rod bend test (Section 5 (*b*)) is machined, at least one of its original surfaces shall be retained."

Section 12.—Revise the note as indicated above for Section 12 in Specification B 12.

Standard Specification for Seamless Copper Bus Pipe and Tube (B 188 – 54):

The proposed revisions in this specification comprise deletion of reference to Specification B 251 in Sections 2 and 9, and the inclusion in Specification B 188 of all the requirements of B 251 that are applicable. The applicable tables from Specification B 251 have been included in Specification B 188 after deleting the $\frac{1}{8}$-in. pipe size from Table I and the $\frac{1}{4}$-in. water tube size from Table II. Table III of B 251 has been replaced with Table I of the Proposed Tentative Specification for Threadless Copper Pipe which is appended hereto,[1] and Tables VI and VII have been added omitting the first column of diameter tolerances in Table VI and combining the first two lines in Table VII. The revised specification is appended hereto.[2]

Standard Specification for Copper-Beryllium Alloy Plate, Sheet, Strip, and Rolled Bar (B 194 – 52):

Section 6(a).—Add a sentence to read: "Tension test specimens shall be taken so that the longitudinal axis of such specimens is parallel to the direction of rolling."

WITHDRAWAL OF STANDARD

The committee recommends that the Standard Specification for Seamless Brass Boiler Tubes (**B 14 – 54**) be withdrawn since the material is no longer in use.

APPENDIX II

A MATHEMATICAL FORMULA FOR THE CALCULATION OF THE TENSILE STRENGTH OF COPPER-SILICON-MANGANESE-IRON ALLOY

BY G. H. BOHN[1]

SYNOPSIS

This paper presents experimental data to show that the tensile strength of the copper-silicon-manganese-iron alloy can be predicted to close limits from analysis by means of a mathematical formula. This prediction covers three conditions: (1) all weld metal, (2) base metal after welding, and (3) base metal annealed at various temperatures. To predict tensile strengths for a single or double element alloy is not difficult, but this paper gives the methods used to predict the tensile strength for a particular four element alloy that could possibly be used for other alloys. The mathematical formula for this alloy is:

$$\text{Tensile strength} = K_1 + K_2\,((\%\ \text{Si}) + (\%\ \text{Fe} \times 1.25) - (\%\ \text{Mn} \times 0.25)).$$

A great many metals specified to be in accordance with ASTM specifications are used for ASME welded pressure vessels. This is particularly true of alloy A, copper-silicon plate and sheet according to Standard Specification B 96.[2] This alloy was originally approved for Code pressure vessels by The American Society of Mechanical Engineers in 1932, and the tensile strength of the base metal and weld was set at 52,000 psi minimum. This could not always be met, and in 1937 the tensile strength was lowered to 50,000 psi minimum. Trouble was still encountered in not always meeting this lowered figure. What made this problem puzzling was the fact that the welded test plates were rupturing in the base metal inches away from the weld, thereby developing 100 per cent welded plate strength. The solution to the problem is given in this paper.

The term "copper-silicon-manganese-iron" has been abbreviated to "copper-silicon" in the following discussion.

Tension Test Specimens:

There are certain tension test specimens that will be referred to in the following discussion that are familiar to designers of welded ASME Code vessels, as follows:

1. *Reduced Section Tension Test Specimen.*—The ASME defines this specimen for welded plate in the 1952, Section IX, Welding Qualifications of the Boiler and

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[1] Design and Metallurgical Engineer, Linde Air Products Co., Division of Union Carbide and Carbon Corp., Tonawanda, N. Y.

[2] Standard Specification for Copper-Silicon Alloy Plate and Sheet for Pressure Vessels (B 96 – 54), 1955 Book of ASTM Standards, Part 2, p. 139.

TABLE I.—FOUR 0.875-IN. THICK PLATES.

Heat	Test Plate Number	Type of Tension Specimen	Tensile Strength, psi	Plate Chemical Analysis, per cent			
				Copper	Silicon	Manganese	Iron
			BASE METAL TESTS (ANNEALED AT 1067 F)				
No. AB1	1	RS	63 150[a]	95.10	3.54	1.22	0.10
High silicon	94	RS	62 900				
High manganese	94	Rd	63 300				
			63 900				
			Average 63 300				
No. AB2	95	RS	57 300	95.66	3.05	1.19	0.08
Low silicon	95	Rd	58 300				
High manganese			Average 57 500				
No. AB3	3	RS	60 600[a]	95.73	3.25	0.91	0.08
High silicon	96	RS	60 700	95.77	3.24	0.87	0.10
Low manganese		Rd	61 300		Recheck		
			Average 60 900				
No. AB4				96.10	2.84	0.89	0.11
Low silicon							
Low manganese	97	Rd	56 800				
			WELDED PLATE TESTS[b]				
No. AB1	94	FS	57 600				
	99	FS	58 000				
			Average 57 800				
No. AB2	95	FS	50 500				
	95	FS	52 000				
	100	FS	51 500				
	100	FS	51 400				
	100	RS	51 200				
	100	RS	51 300				
			Average 51 300				
No. AB3	96	FS	54 900				
	96	FS	55 800				
	101	FS	54 900				
	101	FS	55 300				
	101	FS	55 000				
			Average 55 200				
No. AB4	97	FS	50 500				
	97	FS	50 900				
			Average 50 700				

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[a] Tension tests made by American Brass Co., all others by Linde Air Products Co.

[b] All fractures in the welded plate tests were in the base metal.

Pressure Vessel Code. The standard over-all length is approximately 10 in., and the reduced section is 1.500 in. wide. This is very similar to Fig. 5 of ASTM Methods E 8.[3] In all cases when the specimen was taken from a welded plate, the weld reinforcement was milled flush with the base metal as required by the ASME Code. The abbreviation "RS" will be used in the various tables.

2. *Full Section Tension Test Specimen.*—This specimen is not given in the present 1952 ASME Section IX. However, it was used in this investigation and is the same as the reduced section tension test specimen just described except that the weld reinforcement was left on "as welded" instead of being milled flush with the plate. This was necessary in some cases to make the test specimen rupture in the base metal instead of in the weld. The abbreviation "FS" will be used in the various tables.

3. *Round Tension Test Specimen.*—The ASME describes this specimen by Fig. 5.1(*c*) in the 1952 Section IX Welding Qualifications. The center portion is given as 0.505-in. diameter and the over-all length as 4 in. This is very similar to the top specimen in Fig. 8 of ASTM Methods E 8.[3] The abbreviation "Rd" will be used in the various tables.

The round tension test specimens for the tests on the weld metal were all weld metal. The specimens were taken either from an all weld metal or entirely in the weld of a thick welded plate.

Chemical Analysis:

The tables listing the test data state in all cases whether the chemical analysis was of the cake, plate, or weld metal. The usual mill practice for the cake analysis is to take a liquid ladle sample at the time the cake is poured, pour this into a small mold, and then take drillings from the solid sample for the analysis sample. The cake might be for making welding rod or plate. For the "plate" analysis, drillings were taken from the test plate. For the "weld" analysis, drillings were taken from the center of the weld metal.

Preliminary Tension Tests:

The first technical investigation on the copper-silicon alloy was made in 1935 for the purpose of determining, if possible, what controlled the tensile strength of the welded plate. It appeared that it was the chemical analysis, but there was no proof.

Four plates were processed exactly the same but with varying chemical compositions. The mill used the same size slab, the same rolling reductions, the same size and thickness of plate, and the same annealing temperature and time. Then the shop used the same bevel for welding, the same welder, the same welding technique, and the same welding rod for all four plates. The only variable therefore was chemical composition.

The four test plates were all 0.875-in. thick and the chemical composition was purposely made as follows:

Heat No. 1...	high silicon, high manganese
Heat No. 2...	low silicon, high manganese
Heat No. 3...	high silicon, low manganese
Heat No. 4...	low silicon, low manganese

with an attempt to keep the two high-manganese contents the same, and the two low-manganese contents the same. The first three plates were cut in two and welded approximately one month apart to see if the results could be duplicated. Table I gives the detailed test data.

Examining the results in Table I, the following was learned:

1. The base metal tensile strengths for several specimens for a given heat were very close and were independent whether

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[3] Tentative Methods of Tension Testing of Metallic Materials (E 8 – 54 T), 1955 Book of ASTM Standards, Part 2, p. 1246.

a reduced section or round type of specimen was used.

2. The tensile strengths for welded plates for the three heats were very close, even though welded one month apart.

3. Comparing plates, heats Nos. 1 and 2, which have practically the same manganese and iron contents, it is to be noted that for an increase of silicon content of 0.49 per cent the average base metal strength increased 5800 psi and the average welded strength 6500 psi. This means an increase of over 1000 psi for each 0.10 per cent increase in silicon content.

4. Similarly, comparing plates, heats Nos. 3 and 4, which have practically the same manganese and iron contents, it is to be noted that here again the tensile strength of the base metal and welded plate increased approximately 1000 psi for each 0.10 per cent increase in silicon content.

This preliminary test gave valuable information on how to conduct future tests and also showed that increasing the silicon definitely increased the tensile strength of the alloy.

However, before proceeding with more test work, it was necessary to first determine what effect the crosshead speed of the tension testing machine had on the values for the tensile strength. This is particularly important for the copper-silicon alloy because this alloy work hardens readily.

Crosshead Speed of Tension Machine:

In December, 1935, a heat rolled into 0.875-in. thick plates and annealed at 575 C had several reduced section tension test specimens made from each plate and these were subsequently tested at different speeds by three different laboratories.[4] The data proved that with crosshead speeds of either 0.32 or 0.051 in. per min throughout the test tensile strength did not change. The yield point, however, did increase about 75 per cent for the slower speed. Also, the crosshead speed could be retained at a rate of 1.13 in. per min above the yield point without any effect on the tensile strength. The most heartening data was that the tensile strength results from the three laboratories varied only approximately 1000 psi.

Development of Mathematical Formula:

Once it was known what the crosshead speed of the testing machine should be, test work was resumed. Tests were made not only on the welded plate *versus* plate analysis but on all weld metal *versus* the welding rod analysis. After two years of such testing, it was noted that when the sums of the alloying elements silicon, manganese, and iron, in per cent, were added together and plotted *versus* the tensile strength, the result was a series of parallel lines for any given ratio of silicon to manganese. It appeared that the tensile strength was obeying a definite law or rule. By the method of least squares, the following formula was derived for the strength of the all weld metal, annealed base metal, and the base metal after welding:

$$\text{Tensile strength} = K_1 + K_2\,((\%\ \text{Si}) + (\%\ \text{Fe} \times 1.25) - (\%\ \text{Mn} \times 0.25))$$

$$\text{Or, letting } \alpha = ((\%\ \text{Si}) + (\%\ \text{Fe} \times 1.25) - (\%\ \text{Mn} \times 0.25))$$

$$\text{Tensile strength} = K_1 + K_2\alpha$$

It is to be noticed that the element copper does not appear directly in the formula although it is a part of the alloy. It would seem that when the alloying elements are zero K_1 is equal to the tensile strength of copper. That this is not true will be proved later. K_2, however, is determined by the slope of the plotted test results. The test results did

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[4] The detailed data are available from the author for those desiring them.

TABLE II.—OXYACETYLENE WELDING TEST RESULTS.
Tensile Strength of All Weld Metal *versus* Chemical Analysis and α.

Year Welded	Plate Thickness, in.	Tensile Strength, psi[a]	Analysis of	Heat or Analysis Number	Welding Rod Chemical Analysis, per cent				
					Copper	Silicon	Iron	Manganese	α
1936	0.875	53 300	5 rod ends	N1351	95.49	3.38	0.07	1.06	3.20
1936	0.875	53 600	7 rod ends	N1402	95.24	3.18	0.07	0.98	3.02
		52 500							
1936	0.875	48 400	Rod	N1310-1		2.57	0.07	0.98	
				N1310-2		2.55	0.08	1.01	2.40
1939	0.875	53 900	Rod	Q2609	95.57	3.54	0.14	0.66	3.55
	0.875	54 100							
1939	0.875	53 200	Rod	97	95.54	3.28	0.09	1.02	3.14
1940	0.875	54 000	Cake	Special 3	95.88	3.31	0.15	0.79	3.30
		53 000							
1940	0.875	51 250	Cake	Special 2	96.05	3.03	0.06	0.74	2.92
		51 800							
1940	0.875	49 400	Cake	Special 1	95.88	2.60	0.06	1.35	2.34
		49 150							
1941	0.875	51 150	Cake	Sample 1	95.67	2.95	0.07	1.30	
		52 350	Weld	Weld	95.30	3.05	0.10	1.20	
			Rod	Sample 1	95.33	2.99	0.10	1.24	2.80
1941	0.875	52 150	Cake	Sample 2	95.77	3.07	0.07	1.09	
		51 900	Weld	Weld	95.54	3.20	0.10	0.98	
			Rod	Sample 2	95.40	3.14	0.10	1.02	3.00
1941	0.875	50 000	Cake	Sample 3	95.50	3.30	0.05	1.05	
		50 400	Weld	Weld	95.73	2.99		0.94	
			Rod	Sample 3	95.56	3.00	0.05	0.97	2.82
1941	0.875	52 900	Cake	257	96.04	3.17	0.17	0.56	
		53 200	Weld	Weld	95.91	3.41	0.17	0.51	
			Rod	257	95.69	3.38	0.19	0.48	3.50
1942	0.875	53 900	Cake	358	95.35	3.59	0.06	0.68	3.49
						Nickel 0.15			
1945	Fillet weld	60 400	Rod	Special 5	95.00	3.65	0.74	0.60	4.43
1945	Fillet weld	42 800	Rod	55632	95.02	3.30	1.27	0.52	4.86
		38 200							
1945	Fillet weld	53 500							
		58 300	Rod	Special 2	95.40	3.65	0.77	0.54	4.48
1945	Fillet weld	55 700	Cake	404	95.41	3.74	0.23	0.52	3.90

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[a] All test specimens were round, 0.505-in. diameter. The specimens from the 0.875-in. thick plate were taken longitudinally in weld. The remaining specimens were taken from fillet welds in a welded "T" section.

show that plotting the tensile strength of the base metal for a given anneal *versus* α resulted in single lines instead of a series of straight lines. For the tensile strength of the base metal plate after welding or all weld metal, these single lines have a width or path which can be resolved into average lines. However, the important factor was that the formula showed that to increase the tensile strength, the silicon and iron should be increased and the manganese decreased. Since 1937 when this formula was developed, a considerable amount of experimental work was accomplished on what effect varying the silicon, iron, and manganese contents in the welding rod had on the tensile strength of the weld metal.

TABLE III.—OXYACETYLENE WELDING TEST RESULTS.

Tensile Strength of 0.875-in. Thick Welds *versus* Chemical Analysis and α.

Year Welded	Tensile Strength, psi[a]	Analysis of	Heat or Analysis number	Welding Rod Chemical Analysis, per cent				
				Copper	Silicon	Iron	Manganese	α
1935	54 500 54 300	Rod.......	N1288	95.46	3.46	0.10	0.98	3.34
1935	45 400 46 000	Rod.......	N1287	97.02	1.89	0.07	0.95	1.76
1935	46 700	Rod.......	N1311	97.01	1.99	0.06	0.94	1.83
1935	49 900	Rod.......	N1310-1	96.37	2.57	0.08	0.98	2.43
1936	52 000 52 400 52 000 52 600 51 900 52 600	Rod.......	N1402 Analysis made from ends of seven rods	95.24	3.18	0.07	0.98	3.02
1937	52 100 52 300 52 100 52 800	Rod.......	97	95.54	3.28	0.09	1.28	3.14
1937	52 800 53 100	Cake.......	98	95.78	3.26	0.08	1.02	3.10
1940 1939 1939	53 300 54 000 54 300	Rod.......	O-2609	95.57	3.54	0.14	0.66	3.55
1944	51 600	Rod.......	55633	94.99	3.23	1.31	0.51	4.84
1940	53 500	Cake......	153	95.65	3.50	0.15	0.65	3.52
1942	54 900 54 600 53 700	Cake.......	335	95.67	3.46	0.16	0.72	3.48
1943	54 300	Cake.......	360	95.25	3.63	0.19	0.73	3.68

[a] All test specimens were reduced section tensile with fractures in the middle of the weld.

All Weld Metal Tensile Strength versus Analysis or α:

The test work on weld tensile strength *versus* chemical composition or α of the welding rod was accumulated during the period of 1935 to 1948 for oxyacetylene and carbon arc welding. Since then, Heliarc welding has generally superseded these two types of welding, but the fundamental facts are the same for any type of welding. The first step was to have the mill make a chemical analysis on each heat of welding rod, put the heat number on each and every box of rod, put only rod from one heat in each box, and stencil the heat number on each box. Welding rods of varying chemical analyses were then purposely selected for the tests. The usual iron content of this alloy is about 0.08 per cent, but since the formula indicated that the tensile strength could be raised faster by adding iron than by adding silicon, special heats with high iron contents were cast.

The first tests were made on oxyacetylene all weld metal. Round tension test specimens were made from either fillet welds or from the top part of the weld in a 0.875-in. thick welded plate. The tensile strengths of the weld *versus* chemical analysis or α of the welding rod and weld are given in Table II. Several welders were used in these tests.

Additional detailed information on the tensile strength of the weld metal *versus* the chemical analysis of the welding rod are also given in Table III, the test data in this case being based on reduced section tension specimens from welded plate with fractures in the middle of the weld. Again several welders were used in these tests—for instance, for heat No. N-1402 three different welders were used.

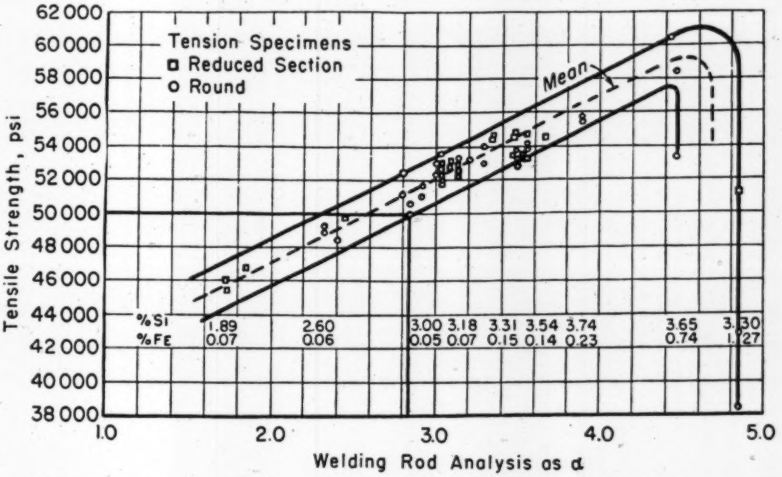

FIG. 1.—Tensile Strength *versus* Chemical Analysis for Copper-Silicon Oxyacetylene Weld Metal.

The test data in Table II prove that the chemical analysis of the welding rod and the final weld metal are for all practical test purposes the same. For instance, the test made in 1941 on sample welding rod No. 1 shows the following comparison of the chemical analysis:

	Copper, per cent	Silicon, per cent	Iron, per cent	Manganese, per cent
Cake	95.67	2.95	0.07	1.30
Welding rod	95.33	2.99	0.10	1.24
Weld metal	95.30	3.05	0.10	1.20

In this particular case it is to be noted that the chemical analysis of the cake was close to both the welding rod and weld chemical analysis, but that did not always hold true. In the first two tests in Table II (N-1351), the ends of the actual welding rods used in the test were analyzed. That, of course, is the proper scientific way to do the job, but it is expensive and was proven to be not necessary. The cake chemical analysis was used in some cases if the tensile strength results came within the plotted path. If this did not hold true, then another check analysis was made on the welding rod or all weld metal.

The tensile strength data in Tables II and III are plotted as Fig. 1. The test results based on round specimens are plotted as small circles and the test results based on rectangular specimens are plotted as small rectangles.

The following is to be noted from Fig. 1: (1) The tensile strength results are the same whether the tensile strength was based on round all weld metal or reduced section tension test specimens taken across a 0.875-in. thick plate. (2) The average or mean line of the path shows that the tensile strength of the oxyacetylene weld can be predicted to approximately ±500 psi or 1 per cent. (3) The test data follow a straight-line path up to a certain point. There is an alarming drop in tensile strength when α is 4.5, and that drop occurs when the iron content is over 0.75 per cent. This trouble can be partially explained by the fact that the original iron does not seem to stay in the weld metal with high iron contents. For instance, it was very difficult to check the iron content of the weld when the rod had 1.25 per cent iron because some of the iron came out of solution and was free. (A magnet picked up free iron in the weld.) ASTM Specification B 96[2] permits a maximum iron content of 1.60 per cent which is satisfactory for base metals not welded but is not desirable for welding, as Fig. 1 shows. That this trouble is due to iron can be proven by comparing the silicon and iron contents given at the bottom of the curves. For instance, compare the following two test data:

Silicon, per cent	3.30	3.31
Iron, per cent	1.27	0.15
Tensile strength, psi	38 000 43 000	53 500 average

(4) Figure 1 shows a horizontal line from 50,000 psi to the lower limit of the curve band, then down to an α value of 2.82. Since the ASME Code requires a minimum weld strength of 50,000 psi, the minimum welding rod analysis for oxyacetylene welds expressed as α is 2.82.

Figure 1 was plotted as tensile strength *versus* the welding rod α in the mathematical formula. To determine the coefficients K_1 and K_2 in the formula for Fig. 1, two points on the average line are selected. For instance, at a tensile strength of 47,000 and 58,000 psi, α is 2.00 and 4.20, respectively. Substituting these values in the basic formula, it is determined that $K_1 = 37{,}000$ and $K_2 = 5000$.

Therefore, this formula becomes:

$$\text{Average tensile strength} = 37{,}000 + 5000\ ((\%\ \text{Si}) + (\%\ \text{Fe} \times 1.25) - (\%\ \text{Mn} \times 0.25))$$

During the investigation on the tensile strength of oxyacetylene welds *versus* chemical composition, a parallel investigation but not so extensive was made on the tensile strength of carbon arc welds. The welding procedure used for all of these carbon arc welds was (1) maximum diameter of welding rod 0.1875 in., (2) maximum amperage 125, and (3) moderate peening of all layers except the last one. A discussion on why this procedure was used would require an entire paper, but suffice it to say that tests which include photomicrographs proved that this produced welds that were as good as annealed base metal in strength and grain size.

TABLE IV.—CARBON ARC WELDING TEST RESULTS.

Tensile Strength of Weld Metal *versus* Chemical Analysis and α.

Year Welded	Test Specimens	Tensile Strength, psi	Analysis of	Heat or Analysis Number	Welding Rod Chemical Analysis, per cent					
					Copper	Silicon	Iron	Manganese	α	
1938	Fillet weld	53 700[a]	Cake.....	99	95.88	3.21	0.11	1.02	3.10	
1943	Fillet weld	61 100[a]	Weld....	405			0.17	0.59		
		61 500[a]	Rod.....		95.82	3.98	0.17	0.49	4.07	
1943	Fillet weld	61 500[a]	Weld....	408			0.25	0.50		
	Fillet weld	59 400[a]	Rod.....		95.62	3.50	0.26	0.56	3.68	
1945	Fillet weld	59 200[a]	Rod.....	Special 5	95.00	3.65	0.74	0.60	4.43	
	Fillet weld	61 300[a]								
1945	Fillet weld	63 900[a]	Cake.....	Special 7	95.09	3.72	0.55	0.56	4.27	
	Fillet weld	62 600[a]								
1945	Fillet weld	51 300[a]	Rod.....	55631	95.12	3.23	1.27	0.52	4.78	
		38 200[a]								
1945	Fillet weld	33 700[a]	Rod.....	55625	97.97	1.66	0.06	0.25	1.57	
		31 700[a]	Rod.....			1.60		0.29	1.61	
									1.59	Average
1942	0.75-in. plate	56 800[a]	Cake.....	340	95.71	3.54	0.15	0.76	3.54	
	0.75-in. plate	56 700[a]								
1943	0.500-in. plate	55 000[b]	Cake.....	391	95.77	3.19	0.16	0.60	3.24	
		54 800[b]				Zn—0.15				
1943	0.500-in. plate	57 900[b]	Cake.....	336	95.74	3.51	0.19	0.67	3.58	

[a] Test specimens were round all weld metal.

[b] Test specimens were reduced section type; all fractured in the middle of the weld.

The tensile strengths of this carbon arc weld metal *versus* α are shown in Table IV and are shown plotted as Fig. 2.

Figure 2 shows the same type of intersection point of 50,000 psi at the lower limit of the path curve as Fig. 1. Since this line intersects at an α value of 3.04, the minimum welding rod analysis for carbon arc expressed as α is 3.04. Since this is higher than the 2.82 required for oxyacetylene welds, this should govern the minimum analysis required for welding rod in accordance with ASTM Specification B 259[5] for copper-silicon rod.

If the same procedure is used for Fig. 2 as in the case of Fig. 1, K_1 will be 12,900 and K_2 will be 12,400. The formula for Fig. 2 will be:

$$\text{Average tensile strength} = 12{,}900 + 12{,}400\ ((\%\ \text{Si}) + (\%\ \text{Fe} \times 1.25) - (\%\ \text{Mn} \times 0.25))$$

Again as with the oxyacetylene weld of Fig. 1, there was an alarming drop in the tensile strength values, but this time with an iron content of approximately

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[5] Tentative Specifications for Copper and Copper-Alloy Welding Rods (B 259 – 52 T), 1955 Book of ASTM Standards, Part 2, p. 439.

0.50 per cent. The fact that this is due to the iron and not silicon or manganese contents can be proven by comparing the following analysis given at the bottom of the curve and Table IV:

Heat	Silicon, per cent	Iron, per cent	Manganese, per cent	Tensile Strength, psi
No. 99	3.21	0.11	1.02	53 700
No. 55631	3.23	1.27	0.52	38 200
No. 391	3.19	0.16	0.60	55 000

Heat No. 55631 is the only heat with a high iron content but a low tensile strength. Since all of these three heats have the same silicon content, the only variables are the iron and manganese content. Comparing heat No. 55631 with heats Nos. 99 and 391, it can be seen that it is not the silicon or manganese contents; therefore, it must be the iron content in heat No. 55631.

However, it is to be noted from Fig. 2

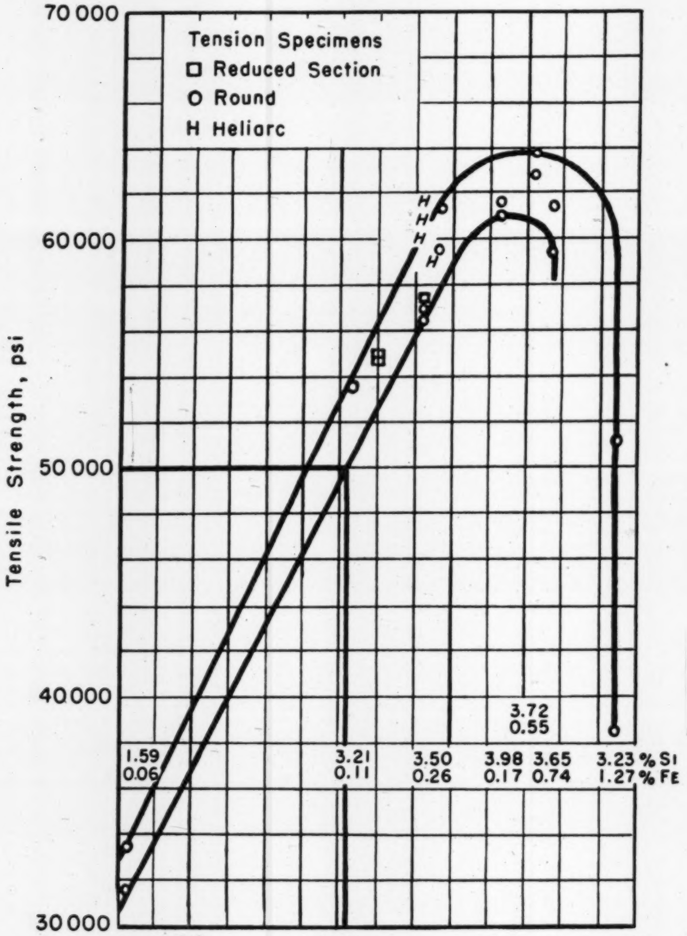

FIG. 2.—Tensile Strength *versus* Analysis for Copper-Silicon Carbon-Arc Weld Metal.

that, when the iron is as high as 0.55 per cent, the highest weld tensile strength of approximately 63,000 psi is recorded. Therefore, a maximum iron content of 0.50 per cent is satisfactory for carbon arc welding.

It is also to be noted that the plotted tensile strength results from Table IV for the 0.500-in. thick plate with reduced section tension specimens (plotted as □), with rupture in the middle of the weld, came inside the same path curve when plotted with the round tension specimens. This is true for carbon arc welding but not oxyacetylene welding, probably because the carbon arc process does not fuse so much of the base metal into the weld as for oxyacetylene.

Up to 1952 the standard thickness used in qualifying welders for ASME Code work was 0.375 in. For several years records were kept of the welding rod, chemical analysis, the plate chemical analysis, and the tensile strength for these welding tests for this thickness. Unfortunately, this record showed that very seldom did any two welders have the same weld tensile strength with the same welding rod and plate. Finally, according to chemical analysis made on the weld metal, it was shown that for both oxyacetylene and carbon arc welding there was a varied blending of the base metal and the welding rod chemical analysis. The result was a weld tensile strength somewhere between the two analyses of rod and plate. For instance, in 1943 there were eleven welders who used the same annealed plate, the same welding rod, and the same welding procedure, yet the tensile strengths varied between 67,800 and 55,400 psi. Of the eleven welders only two pairs of results were close to each other. Therefore, test work on all weld or base metal strength after welding for 0.375-in. thick plate was discontinued.

The test work was therefore concentrated on 0.875-in. thick plates to determine the tensile strength of plates after welding (fractures in the plate) *versus* plate analysis.

Tensile Strength of 0.875-in. Thick Plate After Oxyacetylene Welding versus Chemical Composition or α:

It is essential that the fracture in the tension specimens be in the base metal, if the tensile strength *versus* the analysis of the welded plate is to be determined. When the tensile strength of the weld metal was higher than the base metal, the reduced section tension specimen could be used. However, when the tensile strength of the weld metal was lower than the base metal, the full section tension specimen had to be used. Several welders were used in this test series.

Table V and Fig. 3 give the tensile strengths of 0.875-in. thick base metal after welding *versus* analysis or α of the plate. It is to be noted in Fig. 3 that a horizontal line from the 50,000 psi tensile strength intersects the lower limit of the path curve at an α value of 2.88. This means that for ASME Code pressure vessels the base metal analysis as indicated by α must have a minimum value of 2.88 for ASTM Specification B 96,[2] alloy A.

Using the same procedure as explained for Fig. 1, the mathematical formula for welded plate from Fig. 3 becomes:

$$\text{Average tensile strength} = 21{,}000 + 10{,}600\ ((\%\ \text{Si}) + (\%\ \text{Fe} \times 1.25) - (\%\ \text{Mn} \times 0.25))$$

The width of the curve band is approximately 2000 psi; therefore the average tensile strength has an accuracy of ± 1000 psi or 2 per cent.

This formula holds no matter how the base metal was annealed or whether it was annealed at all, provided the original base metal tensile strength is higher than the final welded tensile strength. Test

TABLE V.—TENSILE STRENGTH OF 0.875-IN. THICK OXYACETYLENE. WELDED PLATE *versus* ANALYSIS AND α.

All fractures were in the base metal.

Year Welded	Type of Specimen	Tensile Strength, psi	Heat or Analysis Number	Plate Chemical Analysis, per cent				
				Copper	Silicon	Iron	Manganese	α
1932	FS	54 200	N5972 of a specimen	95.56	3.23	0.09	1.06	3.08
	FS	53 700						
	FS	54 200						
	FS	54 500						
	FS	53 200						
	FS	52 800						
	FS	54 700						
1933	RS	51 000	N5973 of specimen A444	95.82	3.11	0.07	0.96	2.96
	RS	51 800						
	FS	52 700						
	FS	52 800						
	FS	52 800						
	FS	52 700						
	RS	51 400						
	FS	53 700						
1933	RS	50 400	N5974 of specimen W422	95.90	3.08	0.07	0.94	2.84
	RS	51 100						
	FS	50 800						
	FS	51 500						
1934	FS	52 300	M9609 of cake	95.75	3.07	0.08	1.04	2.91
	FS	52 900						
1934	RS	48 600	N29 of cake	96.04	2.83	0.07	0.84	2.71
	RS	49 800						
1934	RS	50 800	M9610 of plate	95.83	3.04	0.09	1.01	2.90
	RS	51 900						
	RS	51 300						
	RS	50 600						
	FS	51 100						
1934[a]	RS	52 700	N6010 of specimen A514	97.50	3.25	0.06	1.01	3.08
	RS	53 300						
	FS	53 500						
	FS	53 800						
1934[a]	RS	53 200	N6011 of specimen F451	95.68	3.19	0.08	1.06	3.03
	FS	53 000						
	FS	52 100						
1934	FS	53 400	N288 of cake	96.16	2.94	0.11	0.69	3.00
	FS	53 100					check 0.73	
1935	FS	57 600	AB1 of cake	95.10	3.54	0.10	1.22	3.36
	FS	58 000						
1935	FS	50 500	AB2 of cake	95.66	3.05	0.08	1.19	2.85
	FS	52 000						
	FS	51 500						
	FS	51 400						
	RS	51 200						
	RS	51 300						
	RS	50 600						

TABLE V.—*Concluded.*

Year Welded	Type of Specimen	Tensile Strength, psi	Heat or Analysis Number	Plate Chemical Analysis, per cent				
				Copper	Silicon	Iron	Manganese	α
1935	FS	54 900	N1380 of plate	95.77	3.24	0.10	0.81	3.17
	FS	55 800						
	FS	54 900						
	FS	55 300						
	RS	55 000						
	RS	54 300						
1935	FS	50 500	AB4 of cake	96.10	2.84	0.11	0.89	2.76
	FS	50 900						
1935	FS	53 100	AB8, 9 of cake	95.65	3.16	0.14	1.02	3.08
	FS	53 450						
	FS	53 500						
1936	FS	55 000	N1271 of plate	95.56	3.29	0.10	0.94	3.18
	FS	55 900		Above on usual sample				
	FS	54 900						
	FS	55 300		95.59	3.20	0.18	1.02	
	FS	54 800		Above on large sample				
	FS	54 800						
1937	FS	54 500	N6063 of specimen	95.60	3.30	0.06	1.03	3.12
	FS	55 000						
	FS	54 100						
	FS	53 800						
	FS	54 900						
	FS	53 600						
	FS	54 150						
1937	FS	55 500	41A of cake	95.61	3.25	0.13	1.03	3.16
	FS	56 000						
1943	RS	52 600	23 of cake	95.76	3.10	0.09	0.86	3.00
	RS	52 300						
	RS	52 600						
	RS	52 900	of plate			0.09	0.80	
1944	FS	62 000	27 of plate	...	3.34	0.45	0.49	3.78
	FS	61 200						

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[a] 0.8125 instead of 0.875-in. thick.

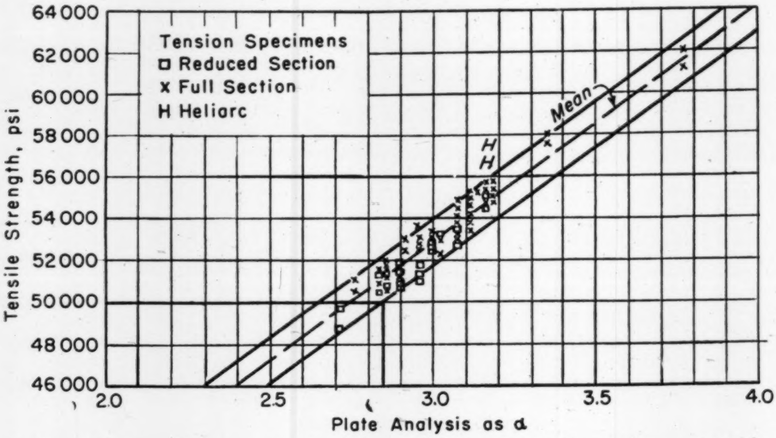


FIG. 3.—Tensile Strength *versus* Analysis for 0.875-in. Thick Oxyacetylene Welded Copper-Silicon Plate.

TABLE VI.—TENSILE STRENGTH OF HELIARC WELDED PLATE *versus* ANALYSIS AND α.

Year Welded	Thickness Plate, in.		Type of Specimen	Tensile Strength, psi	Fracture	Heat	Analysis of	Chemical Analysis, per cent[a]				
								Copper	Silicon	Iron	Manganese	α
1950	0.750	All weld	Rd	59 200	Weld		Rod	95.55	3.52	0.22	0.63	3.63
		Welded plate	RS	56 500	Base metal		Plate	95.87	3.37	0.07	0.71	3.18
		Welded plate	RS	56 900	Base metal							
		Base metal	RS	55 000	Base metal							
1951	0.625	Welded plate	RS	60 000	Weld	No. 673	Rod	95.42	3.65	0.04	0.66	3.54
		Welded plate	RS	56 250	Base metal	No. 5	Plate	94.99	3.79	0.07	1.00	3.78
		Base metal	RS	57 800	Base metal				3.82	Recheck		
1951	0.625	Welded plate	RS	60 600	Weld	No. 673	Rod	95.42	3.65	0.04	0.66	3.54
		Welded plate	RS	60 800	Weld	No. 11	Plate	95.09	3.81	0.07	1.00	3.67
		Base metal	RS	63 500	Base metal				3.85	Recheck		

[a] Analysis of welding rod and plate used for tests.

data to prove this are available, but they are not included as part of this paper since the fact seems obvious.

There are no data available on the tensile strength of the plate after welding, using the carbon arc welding procedure, as most pressure welds made during this test period were oxyacetylene.

There also are not sufficient data available on the tensile strength of the weld metal and the plate after welding for Heliarc or Sigma welding to plot definite curves. Both of these rather new welding procedures have the advantages of both the oxyacetylene and carbon arc welding. They do not require peening like carbon arc welding to produce good welds and yet the physical properties are close to or better than oxyacetylene welding.

Table VI gives test data on some Heliarc arc welds and these tensile strengths have been indicated as an H on Figs. 1 and 2. It is to be noted that the tensile strength of a Heliarc weld is generally higher than for either oxyacetylene or carbon arc.

The 1950 test in Table VI shows that the tensile strength of the all weld specimen (59,200) and the welded plate (56,700) is higher than for the base metal (55,000) even though the base metal specimen was taken from the same test plate. The α value for the rod is 3.63 as compared with 3.18 for the plate; therefore the tensile strength of the weld metal in the middle of the reduced section welded plate specimen is higher than the base metal. The net result is that the fracture in the base metal of the welded plate has a higher tensile strength than the original base metal. This is not unusual for such a combination. It does show the distinct advantage of having the α of the welding rod higher than that for the plate.

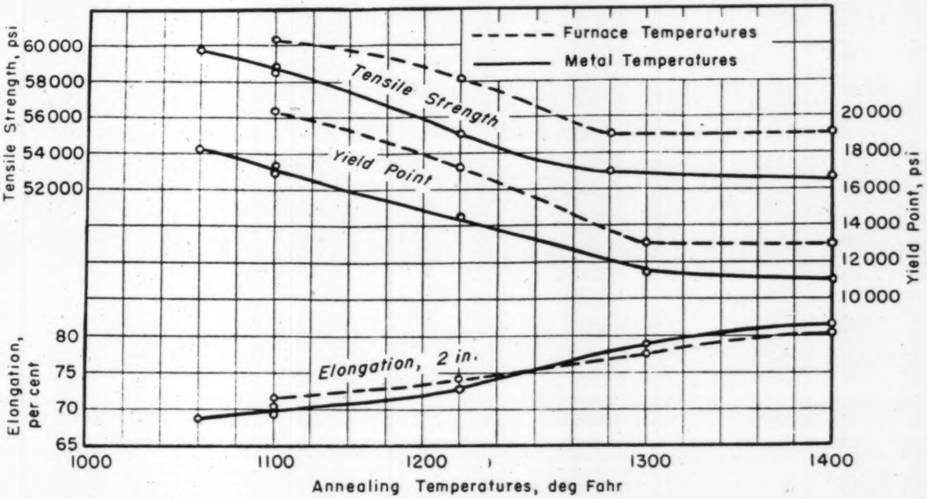


FIG. 4.—Mechanical Properties *versus* Annealing Temperatures for Copper-Silicon 0.875-in Thick Base Metal, Heat No. 23.

Test Methods for Base Metal Tests:

In order to have accurate test data on base metal mechanical properties *versus* annealing temperature and analysis, this investigation showed that certain exact test procedures were necessary.

The first is that the annealing temperature must have close control. Fortunately, two excellent furnaces were available for these tests. One was a Lindberg Electric Cyclone circulating type of furnace with special input controller for ±2.5 F range from the set temperature. This furnace was used for temperatures through 1100 F. Also there was available a General Electric furnace with "reactrol" control which gives very close temperature control. This furnace was used for temperatures above 1100 F.

The second procedure necessary for exact test data is that the temperature must be of the specimen and not the furnace temperature. In this investigation two thermocouples were always used on the test specimens. Both furnaces were equipped to record both the furnace and the specimen temperatures. To show what the difference is, a 0.875-in. plate, heat No. 23, was cut into several specimens. One set was annealed at various temperatures in a research laboratory small furnace where the temperature was determined by a thermocouple in the furnace. Another set was annealed in the two furnaces just described but with thermocouples on the specimens. These two sets of test results are shown plotted as Fig. 4. The tensile strength, the yield point, and the elongation in 2 in. are plotted *versus* annealing temperature. The test results as determined by the specimen temperature are shown in solid lines and those determined by the furnace temperatures in dash lines.

Figure 4 shows that the tensile strength according to the furnace temperature was more than 1000 psi higher than the tensile strength according to the specimen temperature. The yield point and elongation values are at great variance when comparing those taken according to the furnace and the specimen temperature.

This investigation proved that, when the specimen temperature is used, repeat specimens made from the same plate months later will check very closely for a given temperature. A typical case is shown by the double points in Fig. 4 for 1100 F. One specimen was annealed in September, 1943, and the other specimen in March, 1944—the agreement is within 0.50 per cent with test data taken six months apart.

It also became necessary to investigate the effect of length of time at the temperature on the tensile strength. Previous tests had shown that for this alloy (which is an excellent nonconductor) it was necessary to hold the specimen at temperature for at least 2 hr per in. of thickness, but what happens beyond this annealing period was not known. Tensile strength results on a piece of 0.875-in. plate all annealed at 1100 F are shown in table below:

	Test	Furnace	Time, hr	Tensile Strength, psi
Temperature of furnace	No. 1	Large Lindberg	2	63 000
	No. 2	Small laboratory	2	63 000
	No. 3	Small laboratory	3	63 000
	No. 4	Small laboratory	4	62 500
Temperature of specimen	No. 5	Large Lindberg	2	62 100

Test Nos. 1 to 4 were made using the furnace temperature. The first two tests were made in two different furnaces with ordinary controls, using the furnace thermocouple temperature. Both tests were for 2-hr duration. It is to be noted that the tensile strengths are identical. For test No. 3, the time was increased from 2 to 3 hr, and it is to be noted that the tensile strengths are the same as for the two tests for 2-hr time. For test No. 4, the time was increased to 4 hr, and it is to be noted that there was a slight decrease in tensile strength. This was due to the fact that the furnace exceeded 1100 F for a very short time.

However, for test No. 5, the specimen was annealed for 2 hr at 1100 F as determined by a thermocouple on the specimen in the closely controlled Lindberg furnace. Both the specimen and furnace temperatures were recorded on a chart, and it was noted that the furnace temperature was higher and accurately held during the entire 2 hr. Because the furnace temperature is higher than the actual specimen, the tensile strength for test No. 5 was almost 1000 psi lower than for tests Nos. 1 and 2. Since the test results should be a function of the specimen and not the furnace temperature, all tests reported on base metals at various annealing temperatures were made with a thermocouple on the test specimen. This test also proved that 2 to 4 hr annealing at temperature for 0.875-in. thickness gave identical results.

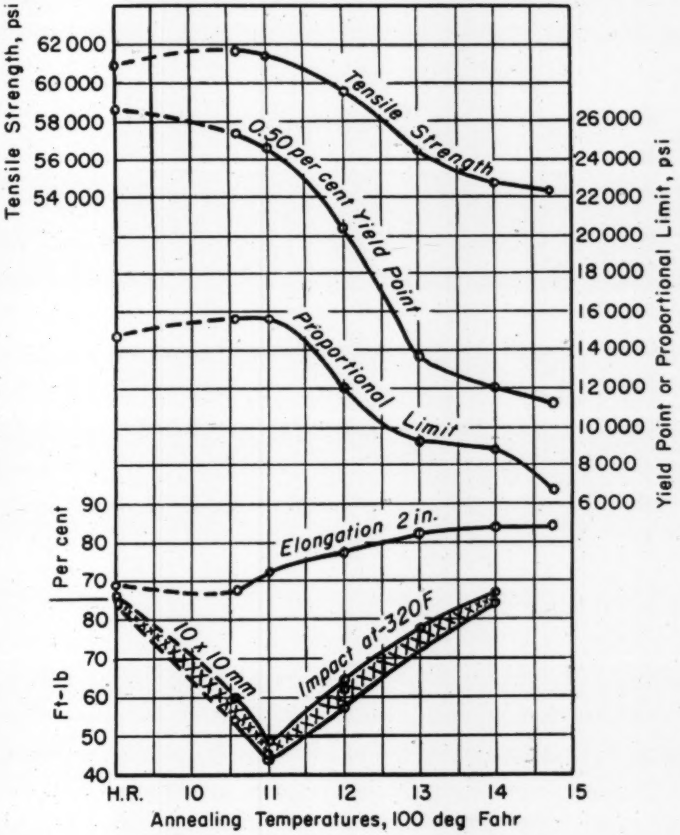
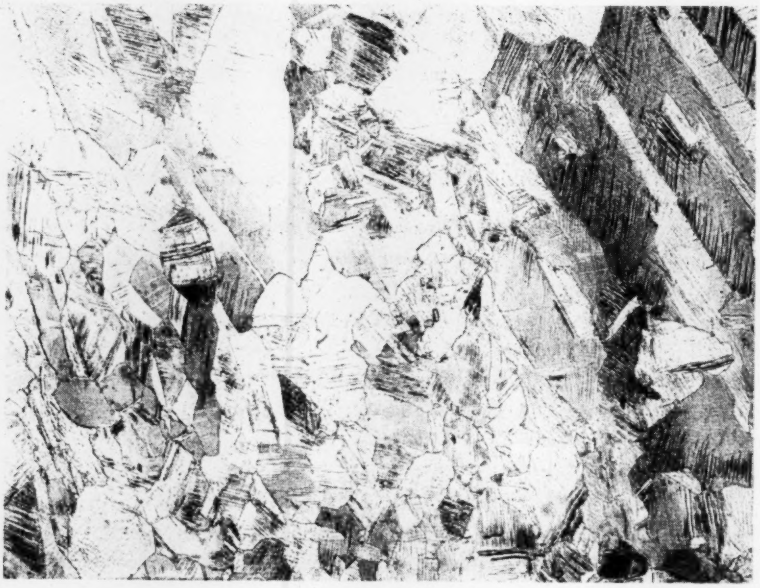


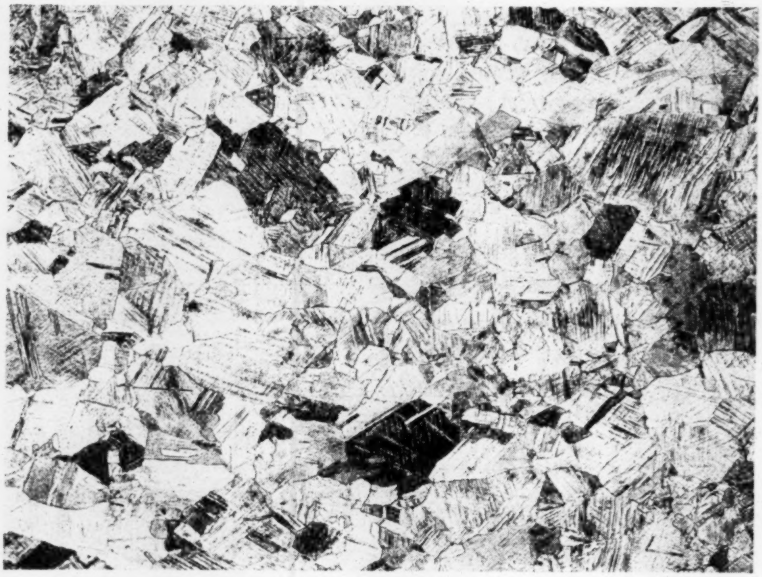
FIG. 5.—Mechanical Properties of 0.75-in. Thick Copper-Silicon Alloy, Heat No. T-6970.

Mechanical Properties of the Base Metal Plate versus Annealing Temperature for 0.75-in. Thickness:

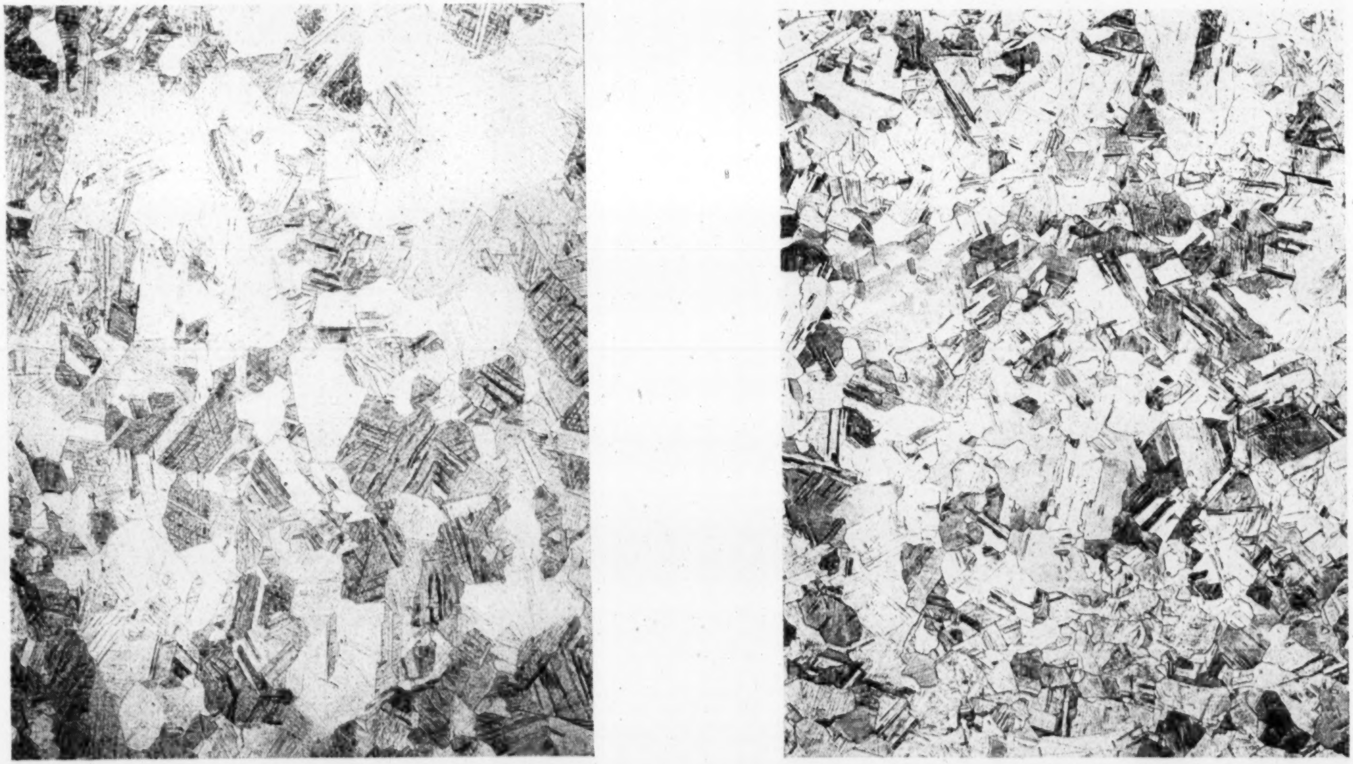
In order to first determine the characteristics of this alloy *versus* both annealing temperature and analysis, it seems advisable to study the mechanical properties for an analysis of this alloy completely for various annealing temperatures. Such a test was made on a 0.75-in



(a) Face—as rolled.

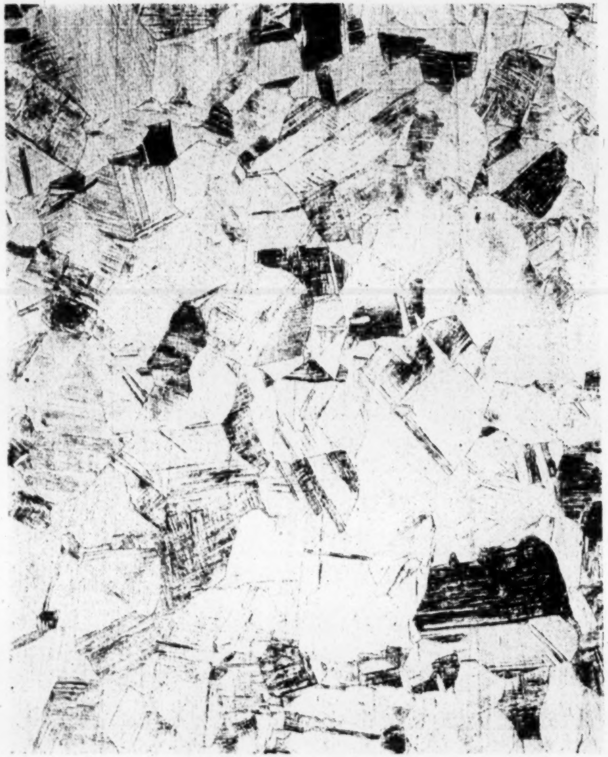


(b) Face—annealed at 1060 F.

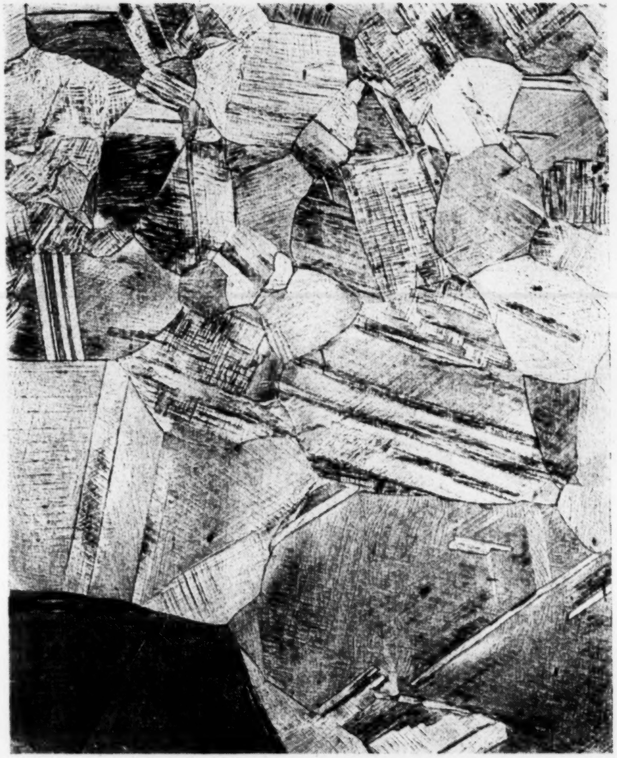


(*c*) Face—annealed at 1100 F. (*d*) Face—annealed at 1200 F.

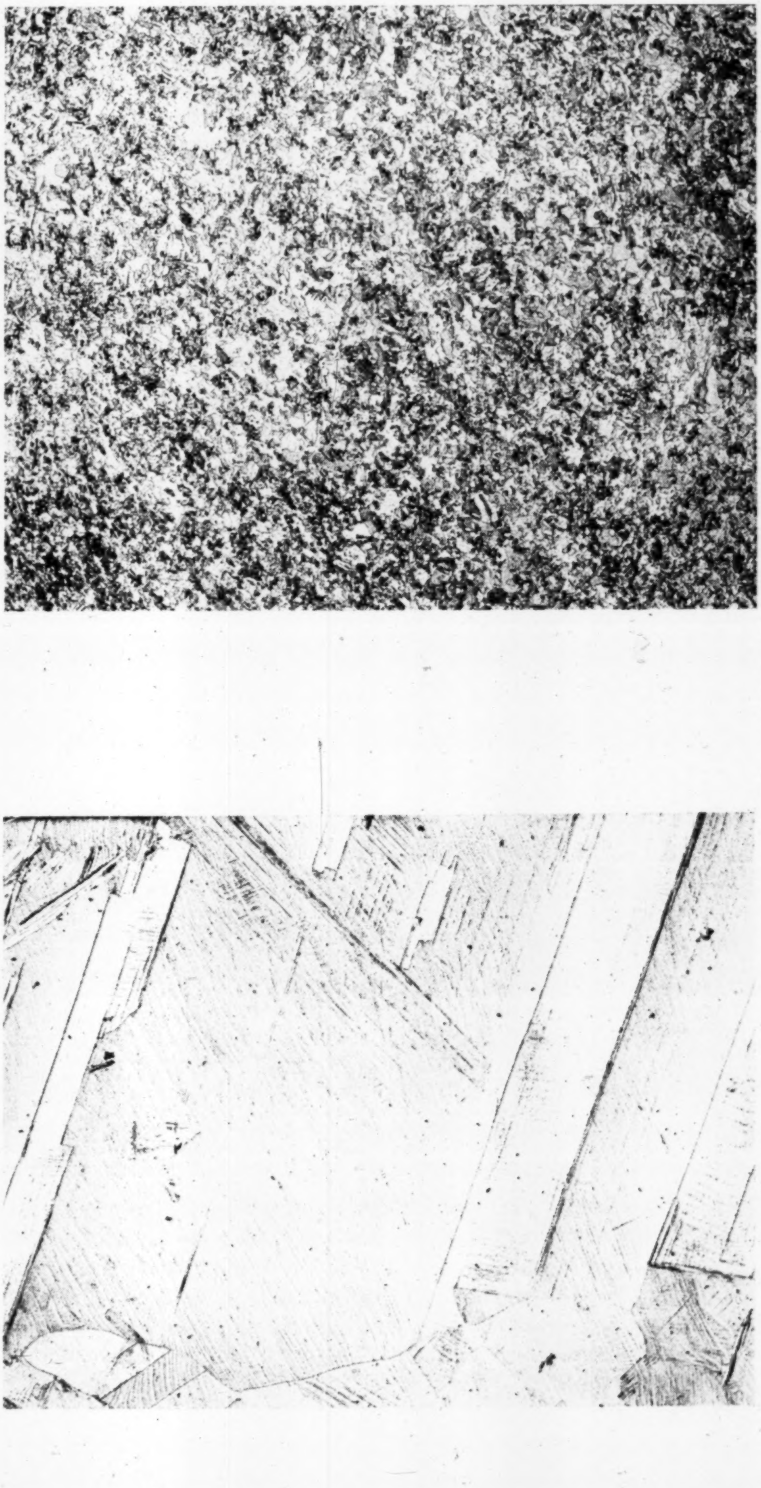
FIG. 6.—Photomicrographs of 0.75-in. Thick Copper-Silicon Alloy, Heat No. T-6970 at Various Temperatures (× 100).



(*a*) Face—annealed at 1300 F.



(*b*) Face—annealed at 1400 F.



(*c*) Face—very large grains as observed in sample annealed at 1400 F. (*d*) Edge—fine grained area along sheared edge of sample annealed at 1060 F.

FIG. 7.—Photomicrographs of 0.75-in. Thick Copper-Silicon Alloy, Heat No. T-6970 at Various Temperatures (× 100).

TABLE VII.—PRELIMINARY TESTS: TENSILE STRENGTH OF 0.875-IN. THICK BASE METAL *versus* ANALYSIS AND ANNEALING TEMPERATURE.

Year	Temperature, deg Fahr	Time, hr	Tensile Strength, psi[d]	Heat	Plate Chemical Analysis, per cent[e]				
					Copper	Silicon	Iron	Manganese	α
1943	1020[b]	...		No. 25	...	3.30	0.37	0.59	3.61
	1200	2	63 000		95.49	3.24	0.38	0.49	3.59
	1200	2	62 500						
	1300	2	60 500						
1943–44	1020[b]	...	58 250	No. 23	...	3.04	0.09	0.80	2.94
	1100	3	57 700						
	1200	3	55 300						
	1300	3	53 000						
1943	1020[b]	...		No. 27	95.59	3.28	0.45	0.40	3.74
	1100	2	68 000		...	3.34	0.45	0.49	3.78
	1200	2	64 250						
	1200	3	64 000						
	1300	2	62 250						
1945	As rolled	...	68 000	No. 4258A	95.24	3.55	0.07	0.82	3.44
	1060	3	65 800						
	1100	3	64 300						
	1200	3	60 500						
	1200	3	60 800						
	1300	3	58 000						
	1400	3	55 200						
1945	As rolled	...	61 100	No. 4258B	95.89	3.14	0.06	0.79	3.02
	1100	3	59 200						
	1200	3	56 000						
	1300	3	53 300						
	1400	3	51 200						
1945	As rolled	...	64 000	No. 4258C	95.47	3.40	0.07	0.85	3.28
	1100	3	61 800						
	1200	3	58 800						
	1300	3	56 500[c]						
	1400	3	53 700						
1949[a]	As rolled	...	60 900	No. T-6970	95.69	3.28	0.11	0.75	3.23
	1100	2	61 400						
	1300	2	56 400						
1949[a]	As rolled	...	39 350	No. 1015	98.08	1.53	0.09	0.26	1.58
	1100	2	40 050		98.15	1.49	0.13	0.26	1.58
	1200	2	39 050						
	1300	2	38 100						

[a] 0.75-in. thickness.

[b] Temperature at which plates were annealed by mill for straightening.

[c] From plotted data for that heat.

[d] All test specimens were round, 0.505-in. diameter.

[e] All chemical analyses were of the test plate.

thick typically hot-rolled plate, heat No. T-6970 of the following chemical analysis:

Copper, per cent	95.69
Silicon, per cent	3.27
Iron, per cent	0.11
Manganese, per cent	0.75
α	3.22

TABLE VIII.—PRELIMINARY TESTS: TENSILE STRENGTH OF 0.375-IN. THICK BASE METAL *versus* ANALYSIS AND ANNEALING TEMPERATURE.

Year	Annealing Temperature, deg Fahr[a]	Tensile Strength, psi[d]	Heat	Plate Chemical Analysis, per cent[e]				
				Copper	Silicon	Iron	Manganese	α
1944	1100	68 000	No. 29		3.38	0.52		
	1200	65 700						
	1300	62 700						
1944	HR[b]	100 900	No. 30	95.38	3.49	0.48	0.74	3.91
	1100	68 800						
	1150	67 200						
	1200	65 600[c]						
	1300	62 500						
	1400	61 800						
1945	HR[b]	84 700	No. 32	95.93	2.88	0.06	0.96	2.72
	1100	57 800						
	1200	54 700						
1943	1100	39 200	No. 1015	97.98	1.55	0.07	0.32	1.56
	1200	37 800						
	1300	37 100						
	1400	36 800						
Copper 1944	1100	30 550						
	1200	30 200						
	1300	30 200						

[a] All annealing times were 2 hr.

[b] High reduction rolling.

[c] From plotted curve.

[d] All tension specimens were reduced section type.

[e] All chemical analyses were of the test plate.

Figure 5 shows the complete mechanical properties of this alloy for this analysis *versus* annealing temperature. The mechanical properties shown are tensile strength, yield strength (0.5 per cent extension under load), proportional limit, elongation in 2 in., and impact. Impact values are plotted as a path, while the remaining properties are plotted as single line curves.

Figure 5 shows a decided change or sharp break in the curves at 1100 F. Photomicrographs were made of the various annealed specimens and eight of these are included as part of this paper (Figs. 6 and 7).

The photomicrographs showed that, although the grain size increased with the annealing temperature, the 1200 F specimen exhibited a finer grain than even the 1060 F specimen. This is due to a recrystallization phenomenon. These specimens for photomicrographs were sheared from the test plate, and it was noted that there was a fine grain structure from the hot-rolled through to the 1200 F specimen on the sheared edge. This is clearly indicated by the fine grain size on the sheared edge after annealing at 1060 F. Hardness tests on the sheared edges and the face of the

TABLE IX.—1954 FINAL TESTS: TENSILE STRENGTH OF 0.375- AND 0.875-IN. THICK BASE METAL *versus* ANALYSIS AND ANNEALING TEMPERATURE.

There was no annealing by mill for straightening.

Thickness, in.	Temperature, deg Fahr	Time, hr	Type of Specimen[a]	Tensile Strength, psi	Heat	Plate Chemical Analysis, per cent[b]				
						Copper	Silicon	Iron	Manganese	α
0.375	As rolled	...	RS	50 400 average of 4	No. 1	95.56	2.42	0.10	0.77	2.36
	1200	1.25	RS	49 700						
	1400	1.25	RS	45 100						
	1100	2	RS	51 700						
	1300	2	RS	46 600						
	1300	2	RS	46 800						
	1400	2	RS	45 500						
0.875	As rolled	...	RS	52 300	No. 1	96.46	2.41	0.11	0.77	2.35
	1060	3	RS	51 300						
	1100	3	RS	50 600						
	1200	3	RS	48 700						
	1300	3	RS	46 700						
	1100	3	Rd	50 000						
	1200	3	Rd	48 750						
	1300	3	Rd	46 600						
	1400	3	Rd	44 700						
	1400	3	Rd	44 000						
	1400	3	Rd	44 350						
0.375	As rolled	...	RS	59 800 average of 4	No. 2	95.75	3.07	0.09	0.86	2.97
	1200	1.25	RS	58 100						
	1300	1.25	RS	53 400						
	1200	2	RS	58 150						
	1300	2	RS	53 500						
	1400	2	RS	52 500						
0.875	As rolled	...	RS	59 200	No. 2	95.74	3.09	0.07	0.86	2.97
	1060	3	RS	59 000						
	1100	3	RS	58 600						
	1200	3	RS	55 500						
	1300	3	RS	53 800						
	1100	3	Rd	57 800						
	1200	3	Rd	55 400						
	1300	3	Rd	53 900						
	1400	3.50	Rd	51 250						
0.375	As rolled	...	RS	68 700 average of 3	No. 3	95.16	3.50	0.08	0.83	3.39
	1100	1.25	RS	67 900						
	1200	1.25	RS	62 800						
	1300	1.25	RS	58 100						
	1100	2	RS	67 400						
	1300	2	RS	57 700						
	1400	2	RS	56 000						
	1400	2	RS	55 900						
0.875	As rolled	...	RS	65 900	No. 3	95.21	3.56	0.07	0.85	3.44
	1060	3	RS	64 700	Recheck	95.19	3.57	0.07	0.86	
	1100	3	RS	64 300						
	1200	3	RS	61 200						
	1300	3	RS	57 700						
	1100	3	Rd	64 400						
	1300	3.5	Rd	58 300						
	1400	3	Rd	55 700						
	1400	3.5	Rd	55 100						

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[a] All round specimens were per ASTM Specification E 8, Fig. 8, 5-in. long threaded.

[b] All chemical analyses were of test plates.

specimens showed the sheared edge to have a higher hardness than the face up to 1200 F.

Tensile Strength of Base Metal Plate versus Annealing Temperature and α:

Test data from the years 1943 to 1948 on the tensile strength of 0.875-in. thick base metal *versus* 1100, 1200, 1300, and 1400 F annealing temperatures for various analyses are given in Table VII. Similar data on 0.375-in. thick base metal are given in Table VIII.

It is generally necessary for the mill to low temperature anneal the plates after final rolling in order to straighten the plates. When this is done, no tests can be made below that annealing temperature. For instance, for heats Nos. 25 and 27 in Table VII, it was known that the mill had annealed the plates for straightening at 1020 F; therefore the first tests were made at 1100 F.

In order to complete the data it was necessary to make additional tests in 1954. The data are given in Table IX. Three heats were made and an attempt was made to hold the silicon at 2.5, 3.0, and 3.5 per cent. A full melt was first made with the silicon approximately 2.5 per cent, then one third was poured, and two plates, one 0.875- and another 0.375-in. thick, were rolled. Then silicon was added to the remaining melt to raise the silicon up to approximately 3.0 per cent. One half was poured and two plates, one 0.875- and another 0.375-in. thick, were rolled. Then silicon was added to the remaining melt to raise the silicon up to approximately 3.5 per cent. One 0.875- and one 0.375-in. plate were rolled. These heats were designated as heats Nos. 1, 2, and 3. There was purposely no mill annealing or mill straightening used for all of these test plates; therefore, complete data from hot-rolled to the 1400 F anneal could be determined. The test plates were bowed, but individual 2 by 12-in. specimens were cut out with a metal cutting saw, straightened, and then annealed at the specified test temperature. These temperatures were 1060, 1100, 1200, 1300, and 1400 F. Reduced section tension specimens were machined and pulled for these annealed and "as rolled" specimens for each heat and thickness. Meanwhile, additional 1 by 6-in. specimens were cut from the 0.875-in. thick plates and annealed at 1100, 1200, 1300, and 1400 F; then round specimens were machined and pulled. Tests made in 1943 proved that at 1200 F it was necessary to hold the temperature for a minimum of 2 hr for complete conversion for the 0.875-in. thickness. In the 1954 tests, some trouble was encountered at 1400 F, and it was found that a minimum of 3.5 hr was usually better to obtain a stable condition. The complete detail test results are given in Table IX.

All tensile strength results in Tables VII, VIII, and IX were first plotted *versus* annealing temperature for a given thickness and analysis to see if there were any obvious errors in the test data. If any test results were doubtful, those tests were repeated and the revised test data recorded. In most tests in Tables VII and VIII and in all tests for Table IX, the analysis of the plate and not the cake were used to determine α.

These tables do not include the yield strength, the elongation, or the reduction in area. These data were recorded and are on file.

It is interesting to note that the 1948 test plate heat No. 4258A in Table VII had almost identical chemical analysis with the 1954 test plate heat No. 3 in Table IX. Following is a comparison of the tensile strengths and chemical analysis of these two plates made nine years apart:

Heat	Year	Chemical Analysis, per cent			
		Silicon	Iron	Manganese	α
No. 4258A	1945	3.55	0.07	0.82	3.44
No. 3	1954	3.56	0.07	0.85	3.44

Heat	Type of Specimen	Tensile Strength, psi			
		1100 F	1200 F	1300 F	1400 F
No. 4258A	Round	64 300	60 800	58 000	55 200
No. 3	Round	64 400	...	58 300	55 700 average
No. 3	RS	64 300	61 200	57 700	...

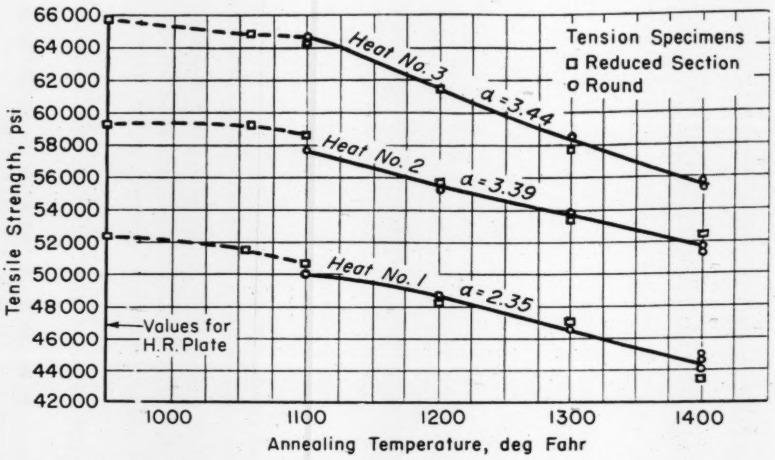

FIG 8.—Tensile Strength *versus* Annealing Temperatures for 0.875-in. Thick Copper-Silicon Base Metal.

When two plates with the same analysis but rolled nine years apart can agree as closely as the above at the various annealing temperatures, this should be partial proof that the tensile strength is a function of the analysis and the annealing temperature.

The tensile strength *versus* annealing temperature from Table IX for 0.875-in. thickness is plotted as Fig. 8. The tensile strength *versus* annealing temperature and α from Tables VII and IX for 0.375-in. thickness are plotted as Fig. 9. Similarly, the tensile strength *versus* annealing temperature and α from Tables VII and IX for 0.875-in. thickness are plotted as Fig. 10. In addition, the mean values from Fig. 3 for oxyacetylene welded plate (with fractures in the base metal) are plotted as a dash line on Fig. 10. Single tensile strength values for heats Nos. 1, 2, and 3 were obtained from Figs. 9 and 10 for 0.375- and 0.875-in. thicknesses and replotted as tensile strength *versus* annealing temperature as Fig. 11. In order to clearly show that α is the controlling factor for this alloy, it is to be noted in Fig. 8 that as the value of α is increased the tensile strength increases for the same annealing temperature and that these curves have more or less the same general shape. The tensile strength of hot-rolled plate depends on the amount of the last reduction and rolling finishing temperature and is a variable. The test results for 1100 F annealing temperature and higher do not seem to be affected by the amount of hot rolling for a given thickness. Tests were made at 1060 F for heats Nos. 1, 2, and 3 to finish the plotted data in Fig. 8. These results at

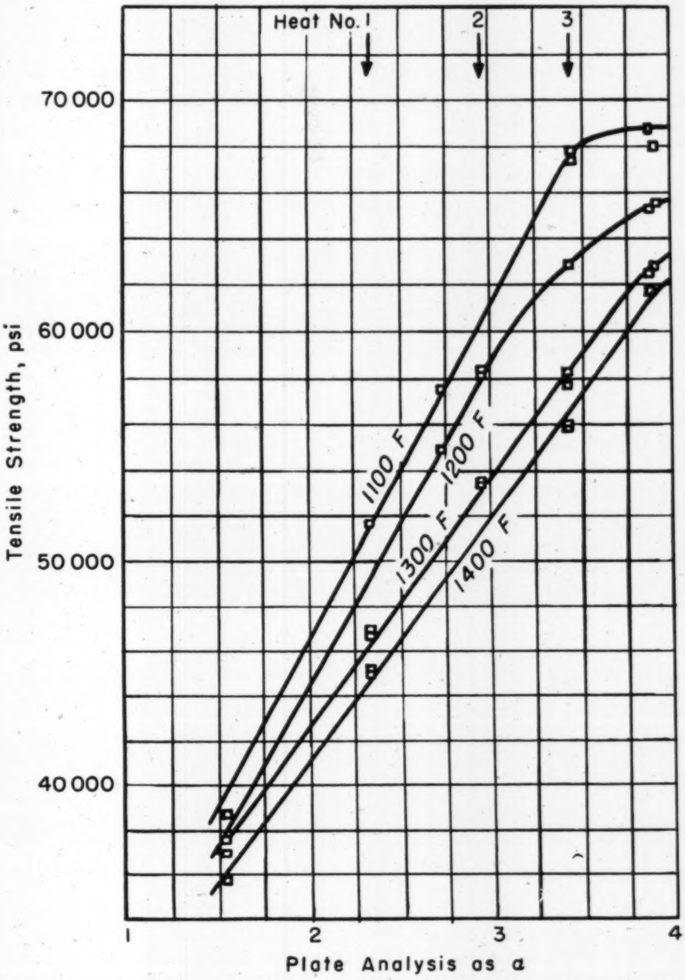

FIG. 9.—Tensile Strength *versus* Chemical Analysis and Annealing Temperatures for 0.375-in. Thick Copper-Silicon Base Metal.

1060 F are affected by the initial hot-rolled tensile strength. It is possible for the tensile strength at the 1060 F anneal to be slightly higher than for the hot-rolled condition, as can be seen from heat No. 2 in Fig. 8 and heat No. T-6970 in Fig. 5. When the tensile strength for the hot-rolled condition is high, it is possible to plot the 1060 F anneal *versus* α as a straight line but not otherwise. The reason for the 1060 F annealing data is that the usual annealing temperature for ASME Code plate material is 1050 to 1100 F.

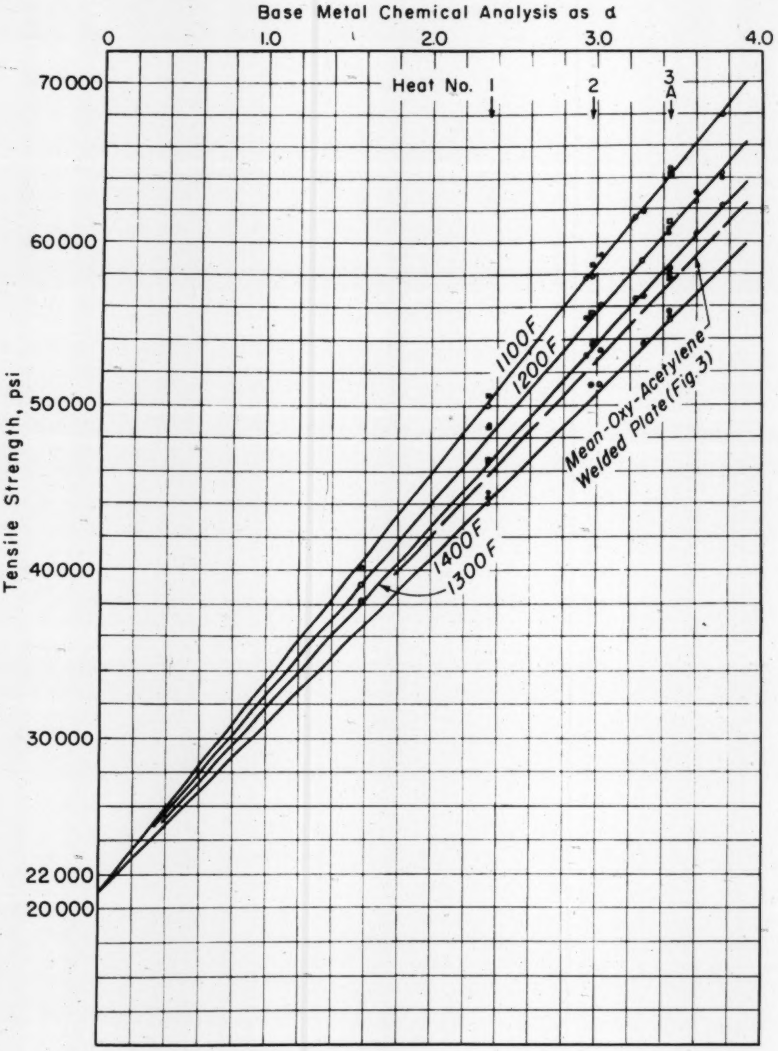

FIG. 10.—Tensile Strength *versus* Chemical Analysis and Annealing Temperature for 0.875-in. Thick Copper-Silicon Alloy Base Metal.

When the test results for the 1100, 1200, 1300, 1400 F anneals for 0.375-in. thickness given in Tables VIII and IX were plotted against α, it was found that the 1100 and 1200 F test values intersected the vertical line with zero α at 16,000 psi—this therefore is K_1 in the formula. Likewise, it was found that the 1300 and 1400 F test values intersected the same line at 20,000 psi—this therefore is K_1 in the formula. These results are shown plotted as Fig. 9 but not to the points of intersection.

The test results for the 1100, 1200, 1300, and 1400 F anneals for 0.875-in. thickness given in Tables VIII and IX and the mean value from Fig. 3 were plotted as Fig. 10. It is to be noted that all five lines intersect at 21,000 psi—this therefore is K_1 for the four anneals and the mean oxyacetylene welded plate. The latter line is approximately one third of the distance between the 1300 and 1400 F anneal and therefore is equivalent

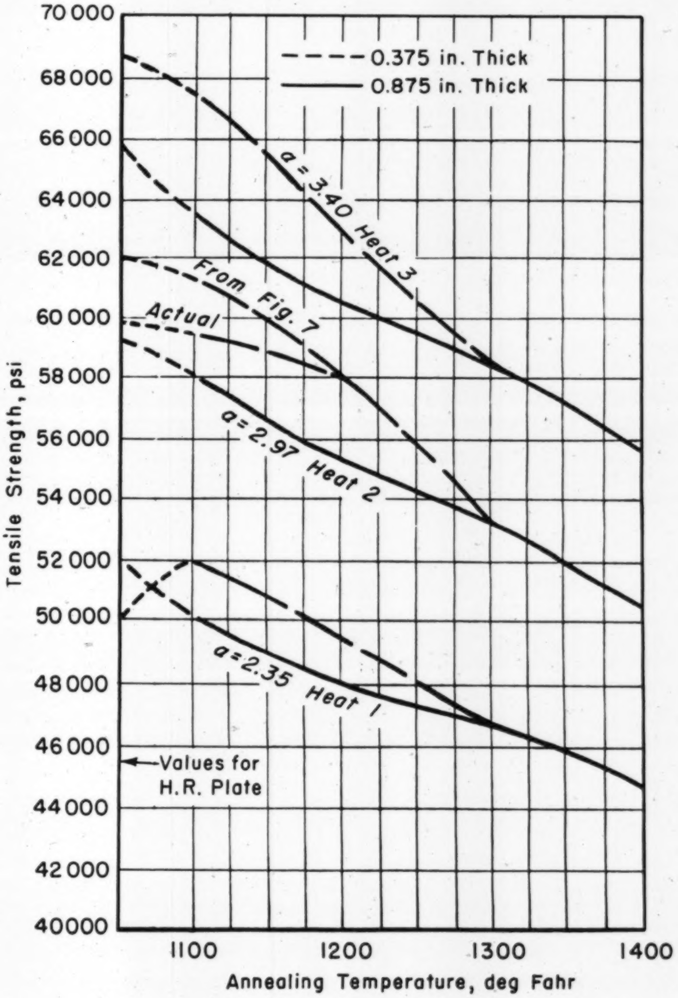

FIG. 11.—Tensile Strength *versus* Annealing Temperature for 0.375- and 0.875-in. Thick Copper-Silicon Alloy Base Metal, Heats Nos. 1, 2, and 3.

to the base metal, furnace annealed at approximately 1333 F.

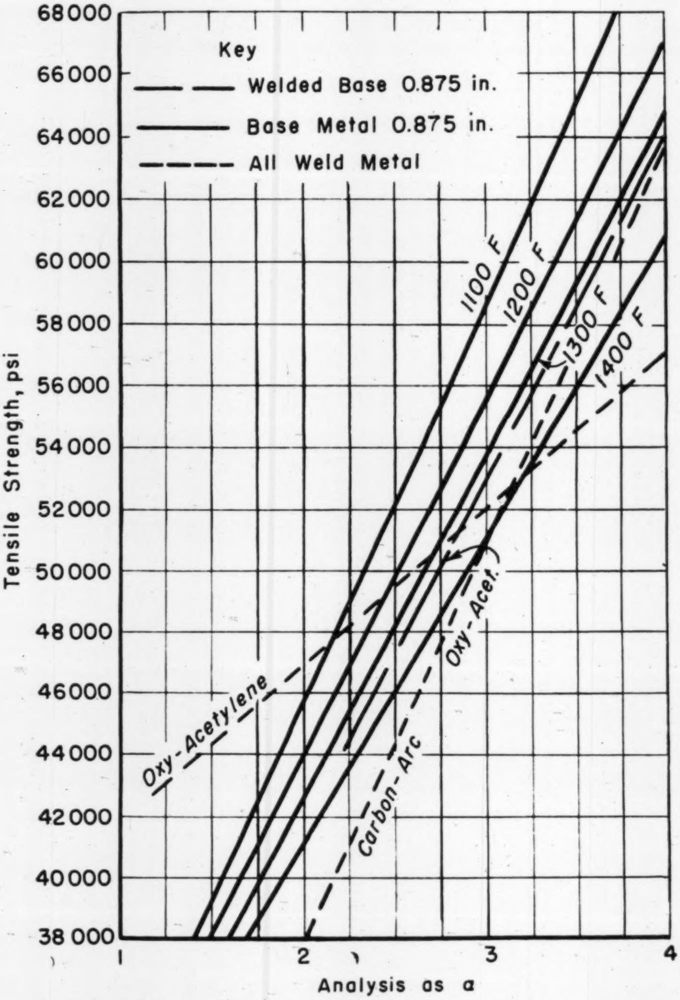

FIG. 12.—Tensile Strength Summaries *versus* Chemical Analysis α for Copper-Silicon Alloy Base Metal and Welded Plate.

One of the original purposes of the tests made and reported in Table IX was to determine the effect of thickness on tensile strength for the same analysis and anneal. Three different heats were made, with a 0.375- and an 0.875-in. thick test plate made from each heat. Figure 11 shows that below 1300 F anneal the 0.375-in. thickness has a higher tensile strength even though the original hot-rolled plate (see heat No. 1) has a lower tensile strength. However, at 1300 F anneal, the tensile strengths for the 0.375- and 0.875-in. thicknesses are the same or tend to be the same. At 1400 F anneal, the tensile strengths for both thicknesses are the same within close limits.

Knowing K_1 in all cases, it is easy to determine K_2 in the formula. With the tensile strength and α known from the plotted data, by substituting in the formula, K_2 can be determined for the various conditions.

Thickness, in.	Annealing Temperature, deg Fahr	Constants	
		K_1	K_2
0.375	1100	16 000	15 100
0.375	1200	16 000	14 100
0.375	1300	20 000	11 300
0.375	1400	20 000	10 700
0.875	1100	21 000	12 400
0.875	1200	21 000	11 500
0.875	1300	21 000	10 900
0.875	1400	21 000	10 000

Figure 12 has been plotted in order to more easily see the relationship on all the test data for 0.875-in. thick base metal and weld. It is to be noted that the base metal plate tensile strengths whether annealed or welded intersect at a common point and therefore have a common K_1 value. This was clearly shown in Fig. 10. The oxyacetylene and carbon arc all weld metal seem to assert individuality and have no relationship to the base metal tensile strengths.

Knowing the chemical analysis and annealing temperature of plate, and rod chemical analysis, the combined plotted data do permit predicting the final welded plate tensile strength and whether rupture will be in the plate or weld.

SUMMARY

This research proved that the copper-silicon-manganese-iron alloy obeys the mathematical formula:

$$\text{Tensile strength} = K_1 + K_2 ((\%\ \text{Si}) + (\%\ \text{Fe} \times 1.25) - (\%\ \text{Mn} \times 0.25))$$

or:

$$\text{Tensile strength} = K_1 + K_2\alpha$$

When the weld test results are plotted as tensile strength *versus* α, the results are paths for all weld and welded plate with fractures in the plate. Assuming the center of the path is the mean, the upper and lower limits of the path are approximately ±1 per cent from the mean. This is close when considering all the personal variables that can be used in welding.

When the test results for the base metal are plotted as tensile strength *versus* α, a series of single lines, one for each annealing temperature, is the result. The deviation of the test results from these lines is approximately ± 0.5 per cent, which is very close. Test results for 0.375- and 0.875-in. thicknesses are different below 1300 F but are almost exactly the same above 1300 F annealing temperature.

Having plotted the test results as straight lines or paths, it is a simple matter to calculate the coefficients K_1 and K_2 in the formula and therefore predict the tensile strength *versus* a formula. A summary of these coefficients follows:

Welded or Base Metal	Thickness, in.	Constants		Annealing Temperature, deg Fahr
		K_1	K_2	
Oxyacetylene all weld	...	37 000	5 000	...
Carbon arc all weld	...	12 900	12 400	...
Oxyacetylene welded plate	0.875	21 000	10 600	...
Base metal	0.375	16 000	15 100	1100
Base metal	0.375	16 000	14 100	1200
Base metal	0.375	20 000	11 300	1300
Base metal	0.375	20 000	10 700	1400
Base metal	0.875	21 000	12 400	1100
Base metal	0.875	21 000	11 500	1200
Base metal	0.875	21 000	10 900	1300
Base metal	0.875	21 000	10 000	1400

Acknowledgment:

The author wishes to thank the various branches of The American Brass Co. and the Electro-Metallurgical Laboratory at Niagara Falls for their most extensive cooperation. Without them, this paper would not have been possible.

APPENDIX III

A HARDNESS CONVERSION TABLE FOR COPPER-BERYLLIUM ALLOY STRIP*

BY G. R. GOHN[1]

SYNOPSIS

A hardness conversion table is given for copper-beryllium alloy strip ranging in thickness from 0.010 to 0.064 in. For material in the as-rolled condition having a tensile strength within the range of 70,000 to 132,000 psi, conversion values, based upon material having the same tensile strength, are given for diamond pyramid hardness numbers taken with both a 2½- and a 5-kg load, as well as for the Rockwell B, and the Rockwell superficial 30T scales. For precipitation hardened material having a tensile strength within the range of 106,000 to 192,000 psi, conversion values are given for the diamond pyramid hardness numbers taken with both a 2½- and a 5-kg load, as well as for the Rockwell C, and the Rockwell superficial 30N scales.

Probably no other property of metals is so widely used as the tensile strength in the evaluation of quality and as the basic acceptance test for practically all metals. However, because of the time consumed in making the tension test, because of the cost of preparing the tension specimens, and because the test is itself a destructive test, hardness tests are frequently used in lieu of tension tests. Depending upon the form and thickness of the metal this may be a Brinell, a Rockwell, a Rockwell superficial, or a diamond pyramid hardness reading. The use of such different methods of hardness testing requires a conversion chart for comparing hardness values obtained on one type of test with those obtained when other loads and different penetrators are used.

Wilson's Chart No. 38 shows the

TABLE I.—CONVERSION VALUES.

	Wilson's Chart No. 38	Hardness Conversion Chart for Cartridge Brass (E 33 - 42)[a]	Hardness Conversion Chart for Nickel and High-Nickel Alloys (E 93 - 52)[b]
Diamond pyramid hardness number	...	140	140
Rockwell hardness number:			
B Scale	76	76.0	76
F Scale	...	100.5	99.5
Rockwell superficial hardness number:			
15T Scale	...	85.5	84.0
30T Scale	67.5	67.0	65.5
45T Scale	49.0	50.0	47.5
Brinell hardness number	122	122	139

[a] 1952 Book of ASTM Standards, Part 2, p. 1268.

[b] 1952 Book of ASTM Standards, Part 2, p. 1299.

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* Presented at the Fifty-eighth Annual Meeting of the Society, June 26–July 1, 1955.

[1] Member of Technical Staff, Bell Telephone Laboratories, Inc.; Chairman of Special Task Group of Subcommittee W-1, of ASTM Committee B-5 on Copper and Copper Alloys, which carried out the investigation of the hardness characteristics of copper-beryllium alloy strip upon which this work is based.

general relationship among a number of the different hardness tests. However, since this conversion chart is a composite one representing tests on both ferrous and non-ferrous materials, it is not surprising that the conversion values for any given material will vary somewhat from those given in the chart. This is illustrated in Table I.

Some years ago a Task Group consisting of Messrs. H. S. Freynik (Riverside Metal Co.), G. R. MacDonald (General Electric Co.) and W. H. Sparrow (Sperry Gyroscope Co.) with G. R. Gohn (Bell Telephone Laboratories, Inc.) as chairman was appointed under Subcommittee W-1 of ASTM Committee B-5 on Copper and Copper Alloys to review the Rockwell hardness-tensile strength relationship as given in ASTM Specification B 194 - 46a T[2] and B 195 - 46 T[3] for copper-beryllium alloy strip. The task group was subsequently increased by the addition of Messrs. J. D. MacQueen (International Business Machines Corp.) and L. H. Adam (Frankford Arsenal). The studies of this Task Group led to a revision in the requirements in ASTM Specification B 194 - 46a T[2] for both the tensile and hardness values and subsequently to the withdrawal of Specification B 195- 46 T.[3] This study also provided the basic data for a hardness conversion chart for copper-beryllium alloy strip, both in the as-rolled and in the precipitation hardened condition.

Outline of Testing Program:

The Task Group first undertook to establish the Rockwell hardness - tensile strength relationship for three lots of copper-beryllium alloy strip prepared by Mr. Freynik. Each lot was rolled from material which conformed to the chemical composition requirements specified in ASTM Specification B 194 for the ternary copper-beryllium alloy. One lot was in the as-rolled condition; one lot was precipitation hardened for 3 hr at 600 F; and one lot was precipitation hardened for 3 hr at 525 F. Each lot was supplied in 12 different thicknesses—as 0.010, 0.0126, 0.016, 0.020, 0.025, 0.032, 0.036, 0.040, 0.045, 0.051, 0.057, and 0.064 in. strip—and in six different tempers—soft, quarter hard, half hard, three quarters hard, hard, and extra hard. These were tested by the laboratories with which the four original members of the Task Group were affiliated.

Analysis of the data indicated differences among the results obtained in different laboratories which made it undesirable to average all of the test results. While the data from these tests showed too much variation among readings of the different laboratories for setting up final specification limits for the hardness - tensile strength relationship, it did establish the following:

1. The Rockwell F and Rockwell superficial 15T scales gave hardness - tensile strength relationships which failed to give good discrimination in hardness for substantial increases in tensile strength for the as-rolled copper-beryllium alloy strip.
2. A similar limitation was observed in the Rockwell A and the Rockwell superficial 15N scales when used to test precipitation hardened copper-beryllium alloy strip.
3. The Rockwell G and the Rockwell superficial 45T and 45N scales, while showing suitable discrimination in hardness for increasing tensile strengths, gave no better discrimination than did the Rockwell B and C scales or the Rockwell superficial 30T and 30N scales; hence the use of G, 45T, and 45N scales was deemed superfluous.

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[2] 1946 Book of ASTM Standards, Part I-B, p. 414.

[3] 1946 Book of ASTM Standards, Part I-B, p. 418.

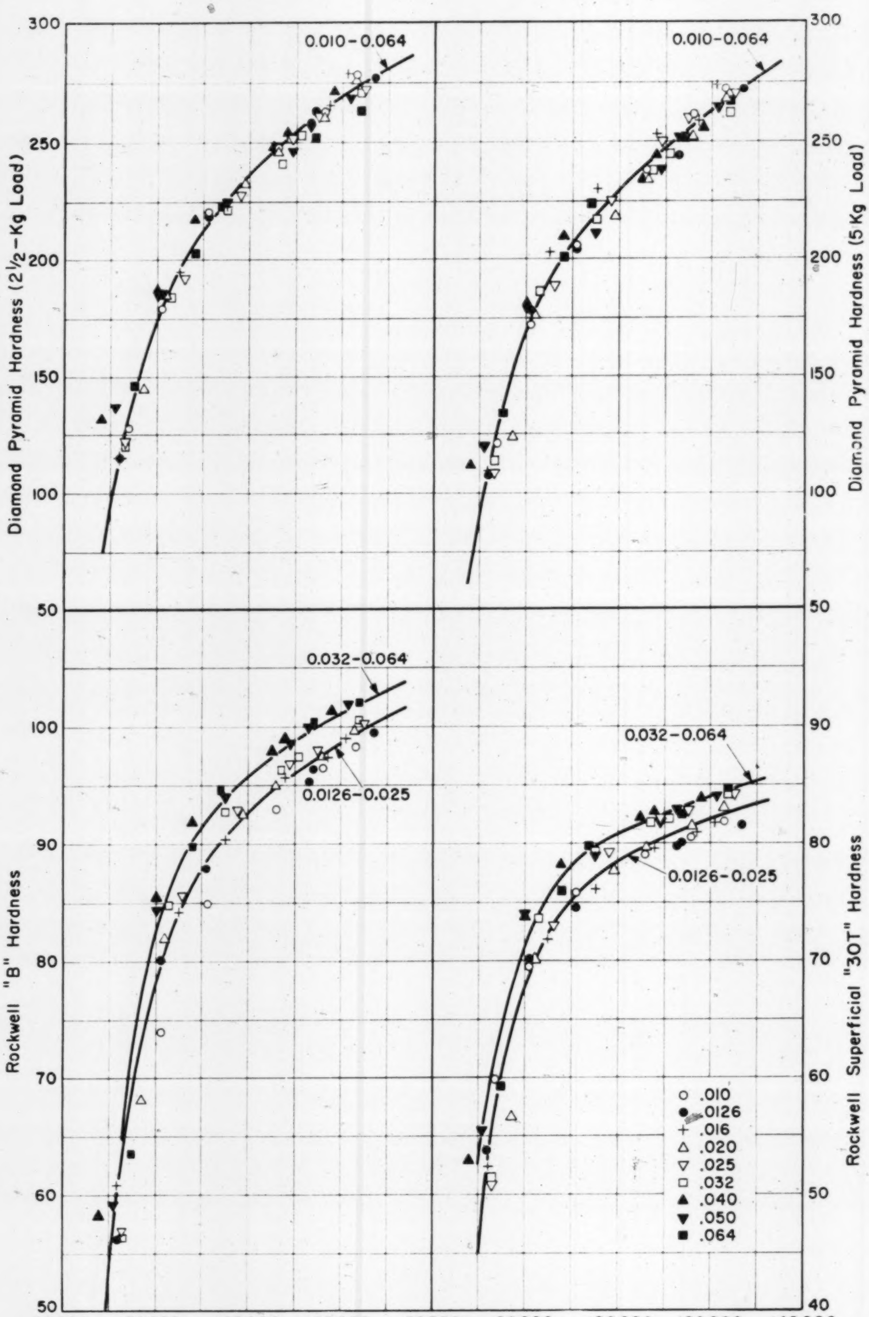

FIG. 1.—Hardness-Tensile Strength Relationship for As-Rolled Copper-Beryllium Alloy Strip. Average curves for range of thickness in inches as indicated

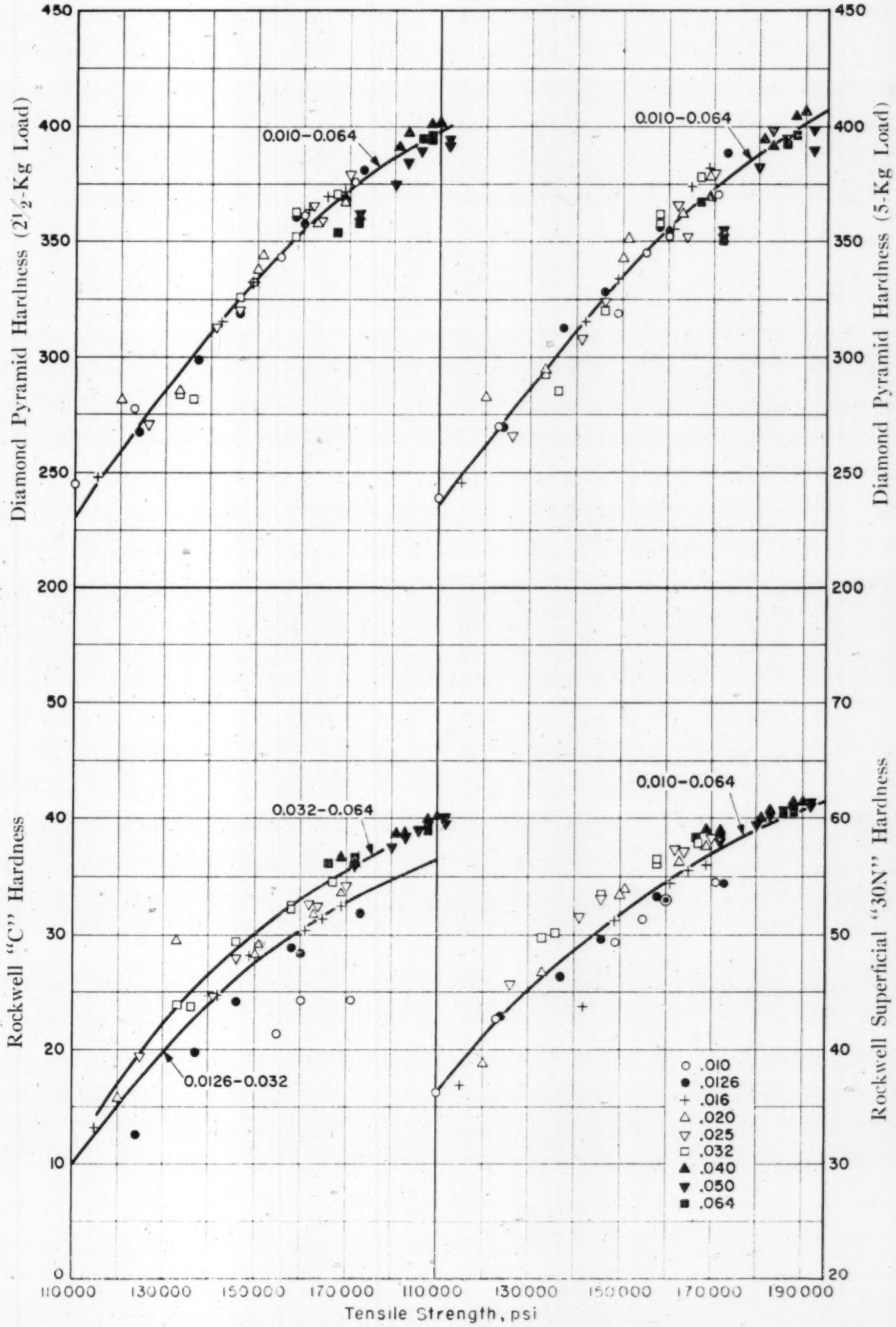

FIG. 2.—Hardness-Tensile Strength Relationship for Precipitation Hardened Copper-Beryllium Alloy Strip.

Average curves for range of thickness in inches as indicated.

TABLE II.—SUMMARY OF HARDNESS - TENSILE STRENGTH DATA ON COPPER - BERYLLIUM ALLOY.

Nominal Thickness, in.	Temper	As Rolled					Aged 3 Hr at 600 F				
		Rockwell "B" Hardness	Rockwell Superficial "30T" Hardness	Diamond Pyramid Hardness		Tensile Strength, psi	Rockwell "C" Hardness	Rockwell Superficial "30N" Hardness	Diamond Pyramid Hardness		Tensile Strength, psi
				2½-kg load	5-kg load				2½-kg load	5-kg load	
0.010	0	...	59.9	128	121	74 000	...	36.2	245	239	110 000
	1	73.9	69.6	179	172	81 000	...	42.6	277	270	123 000
	2	84.8	75.8	220	205	91 000	...	49.3	333	318	149 000
	3	92.8	79.0	247	238	106 000	21.3	51.3	343	345	155 000
	4	96.4	80.6	263	261	116 000	24.3	53.0	361	352	160 000
	6	98.3	81.9	278	272	123 000	24.3	54.5	376	370	171 000
0.0126	0	56.1	53.9	115	108	72 000	12.6	42.9	268	270	124 000
	1	80.1	70.2	185	178	81 000	19.8	46.4	299	312	137 000
	2	87.8	74.6	219	204	91 000	24.1	49.7	319	328	146 000
	3	95.4	79.7	258	244	113 000	28.4	53.0	358	354	160 000
	4	96.4	80.1	263	252	114 000	28.9	53.2	361	356	158 000
	6	99.5	81.8	277	272	127 000	31.8	54.5	381	388	173 000
0.016	0	60.8	52.5	115	109	72 000	13.3	36.8	248	245	115 000
	1	84.3	71.9	195	203	85 000	24.6	43.7	315	315	142 000
	2	90.4	76.2	223	230	95 000	28.1	51.2	333	334	149 000
	3	95.8	79.6	253	253	108 000	31.4	55.5	370	374	165 000
	4	97.4	81.0	266	259	117 000	30.4	54.5	364	355	161 000
	6	99.0	81.8	279	274	121 000	32.5	56.0	372	382	169 000
0.020	0	68.1	56.6	145	124	77 000	15.8	38.8	281	284	120 000
	1	81.8	70.3	185	176	82 000	29.6	46.7	285	294	133 000
	2	92.6	77.7	234	219	99 000	28.4	53.4	338	343	150 000
	3	95.0	79.7	246	234	106 000	29.2	54.0	344	351	151 000
	4	97.6	81.6	261	252	116 000	31.6	56.3	358	362	163 000
	6	99.6	83.1	277	268	123 000	33.6	57.6	367	379	169 000
0.025	0	57.0	50.8	122	109	73 000	19.5	45.6	271	266	126 000
	1	85.6	73.0	192	189	86 000	24.6	51.5	313	308	141 000
	2	93.0	79.3	228	225	98 000	28.0	53.1	320	324	146 000
	3	96.9	82.1	252	250	109 000	32.5	57.2	358	352	164 000
	4	98.0	82.8	261	260	115 000	32.6	57.4	365	366	162 000
	6	100.2	84.2	272	270	125 000	34.2	58.3	379	380	170 000
0.032	0	56.4	51.5	121	114	73 000	23.9	50.2	282	285	136 000
	1	84.8	73.6	184	186	83 000	24.0	49.8	284	293	133 000
	2	92.9	79.4	222	217	95 000	29.0	53.3	326	320	146 000
	3	96.4	81.8	241	238	107 000	32.5	56.1	352	358	158 000
	4	97.5	82.2	253	245	111 000	32.4	56.5	363	362	158 000
	6	100.6	84.4	271	262	124 000	34.6	57.9	371	378	167 000
0.040	0	58.2	53.0	132	112	68 000	36.1	58.8	361	354	172 000
	1	85.5	73.7	187	181	80 000	36.7	59.0	370	369	169 000
	2	91.8	78.1	217	210	88 000	38.7	60.7	397	391	183 000
	3	98.0	82.3	248	234	105 000	38.7	60.0	391	394	181 000
	4	99.0	82.7	254	244	108 000	40.2	61.4	402	406	190 000
	6	101.4	83.8	271	256	118 000	39.9	61.4	401	404	188 000
0.050	0	59.2	55.5	137	120	71 000	36.0	58.2	361	354	172 000
	1	84.4	73.9	185	179	80 000	37.5	59.4	375	382	180 000
	2	94.0	79.0	225	212	95 000	39.0	60.7	389	394	186 000
	3	98.4	81.9	246	238	109 000	38.8	60.2	384	398	183 000
	4	99.8	83.0	257	252	113 000	39.5	61.0	394	398	192 000
	6	101.9	84.0	268	264	121 400	40.1	61.3	391	389	192 000
0.064	0	63.5	59.3	146	134	75 000	36.5	58.3	358	350	172 000
	1	89.7	75.9	203	201	88 000	36.2	58.2	354	367	167 000
	2	94.5	79.7	223	224	94 000	39.1	61.0	396	396	188 000
	3	...	...	...	...	...	...	...	...	...	...
	4	100.3	82.6	252	252	114 000	39.2	60.8	395	396	188 000
	6	102.1	84.5	263	267	124 000	39.0	60.6	394	393	186 000

TABLE III.—HARDNESS CONVERSION TABLE FOR COPPER-BERYLLIUM ALLOY STRIP.

As-Rolled						After Precipitation Hardening at 600 F				
Diamond Pyramid Hardness		Rockwell "B" Hardness		Rockwell Superficial "30T" Hardness		Diamond Pyramid Hardness		Rockwell "C" Hardness		Rockwell Superficial "30N" Hardness
2½-kg load	5-kg load	Under 0.0320 to 0.0126 in., incl, thick	0.0320 in. and over thick	Under 0.0320 to 0.0126 in., incl, thick	0.0320 in. and over thick	2½-kg load	5 kg load	Under 0.0320 to 0.0126 in., incl, thick	0.0320 in. and over thick	0.0100 in. and over thick
92	82	51.7	...	43.3	51.3	...	...	...	...	...
94	84	52.5	...	44.0	51.8	...	...	...	...	...
96	86	53.5	...	44.7	52.3	...	...	...	...	...
98	88	54.3	...	45.3	52.8	...	...	...	...	...
100	90	55.0	...	46.0	53.3	...	...	...	...	...
102	92	56.0	...	46.7	53.8	...	...	...	...	...
104	94	56.7	...	47.4	54.3	...	...	...	...	...
106	96	57.2	...	48.2	54.7	...	...	...	...	...
108	98	57.8	...	49.0	55.2	...	...	...	...	...
110	100	58.3	...	49.7	55.7	...	...	...	...	...
112	103.0	58.9	...	50.3	56.2	...	...	...	...	...
114	106.0	60.0	...	51.0	56.7	...	...	...	...	...
116	108.5	61.0	...	51.7	57.1	...	...	...	...	...
118	110.5	61.7	...	52.3	57.6	...	...	...	...	...
120	112.5	62.3	...	53.0	58.2	...	...	...	...	...
122	114.5	63.0	...	54.0	58.7	...	...	...	...	...
124	116.5	63.5	...	54.7	59.2	...	...	...	...	...
126	118.6	64.0	64.4	55.3	59.6	...	...	...	...	...
128	120.9	64.7	65.2	56.0	60.1	...	...	...	...	...
130	123.1	65.3	66.0	56.6	60.6	...	...	...	...	...
132	125.4	66.0	66.8	57.2	61.1	...	...	...	...	...
134	127.5	66.5	67.6	57.7	61.6	...	...	...	...	...
136	129.5	67.0	68.4	58.2	62.0	...	...	...	...	...
138	131.5	67.7	69.2	58.8	62.5	...	...	...	...	...
140	133.5	68.2	70.0	59.4	63.0	...	...	...	...	...
142	135.5	68.7	70.8	60.0	63.5	...	...	...	...	...
144	137.5	69.2	71.6	60.5	64.0	...	...	...	...	...
146	139.5	69.7	72.4	61.0	64.4	...	...	...	...	...
148	141.5	70.2	73.2	61.5	64.9	...	...	...	...	...
150	143.4	70.7	74.0	62.0	65.4	...	...	...	...	...
152	145.3	71.3	74.8	62.5	65.8	...	...	...	...	...
154	147.2	72.0	75.6	63.0	66.2	...	...	...	...	...
156	149.1	72.7	76.3	63.5	66.7	...	...	...	...	...
158	151.1	73.3	77.0	64.0	67.1	...	...	...	...	...
160	153.2	74.0	77.7	64.5	67.7	...	...	...	...	...
162	155.4	74.7	78.3	65.0	68.1	...	...	...	...	...
164	157.6	75.2	79.0	65.5	68.6	...	...	...	...	...
166	159.7	75.8	79.7	66.0	69.0	...	...	...	...	...
168	161.9	76.3	80.3	66.4	69.5	...	...	...	...	...
170	163.9	77.0	81.0	66.8	69.9	...	...	...	...	...
172	165.8	77.5	81.7	67.2	70.3	...	...	...	...	...
174	168.5	78.0	82.2	67.6	70.8	...	...	...	...	...
176	169.5	78.5	82.8	68.0	71.2	...	...	...	...	...
178	170.5	79.0	83.2	68.4	71.7	...	...	...	...	...
180	171.0	79.5	83.8	68.8	72.1	...	...	...	...	...

(Continued on pp. 236-238.)

TABLE III.—*Continued.*

As-Rolled						After Precipitation Hardening at 600 F				
Diamond Pyramid Hardness		Rockwell "B" Hardness		Rockwell Superficial "30T" Hardness		Diamond Pyramid Hardness		Rockwell "C" Hardness		Rockwell Superficial "30N" Hardness
2½-kg load	5-kg load	Under 0.0320 to 0.0126 in., incl, thick	0.0320 in. and over thick	Under 0.0320 to 0.0126 in., incl, thick	0.0320 in. and over thick	2½-kg load	5-kg load	Under 0.0320 to 0.0126 in., incl, thick	0.0320 in. and over thick	0.0100 in. and over thick
182	174.2	80.0	84.2	69.2	72.5	...	...	...	...	...
184	177.4	80.5	84.8	69.6	72.9	...	...	...	...	...
186	180.1	81.0	85.2	70.0	73.4	...	...	...	...	...
188	182.4	81.7	85.8	70.4	73.8	...	...	...	...	...
190	184.5	82.2	86.2	70.8	74.2	...	...	...	...	...
192	186.6	82.8	86.8	71.2	74.6	...	...	...	...	...
194	188.5	83.2	87.2	71.6	74.9	...	...	...	...	...
196	190.5	83.8	87.8	72.0	75.3	...	...	...	...	...
198	192.4	84.2	88.2	72.4	75.6	...	...	...	...	...
200	194.3	84.8	88.8	72.8	76.0	...	...	...	...	...
202	196.2	85.2	89.2	73.1	76.3	...	...	...	...	...
204	198.0	85.8	89.8	73.4	76.6	...	...	...	...	...
206	200.0	86.3	90.2	73.7	76.9	...	...	...	...	...
208	202.0	87.0	90.7	74.0	77.2	...	...	...	...	...
210	204.0	87.4	91.1	74.2	77.5	...	...	...	...	...
212	206.0	87.7	91.6	74.5	77.8	...	...	...	...	...
214	207.9	88.1	92.0	74.8	78.1	...	...	...	...	...
216	209.7	88.6	92.4	75.2	78.4	...	...	...	...	...
218	211.5	89.1	92.8	75.5	78.7	...	...	...	...	...
220	213.5	89.5	93.1	75.8	79.0	220	219.5	*7.5*	...	31.6
222	215.5	89.9	93.4	76.1	79.2	222	221.5	*7.9*	...	32.2
224	217.5	90.4	93.8	76.5	79.5	224	223.5	*8.3*	...	32.9
226	219.4	90.8	94.2	76.8	79.7	226	225.5	*8.6*	...	33.5
228	221.2	91.1	94.5	77.2	80.0	228	227.5	*9.0*	...	34.2
230	223.0	91.4	94.8	77.5	80.2	230	229.5	*9.4*	...	34.8
232	225.0	91.9	95.2	77.7	80.4	232	231.5	*9.8*	...	35.3
234	227.0	92.4	95.5	78.0	80.6	234	233.5	*10.2*	...	35.8
236	229.0	92.8	95.8	78.2	80.8	236	235.5	*10.5*	...	36.3
238	231.0	93.1	96.2	78.5	81.0	238	237.5	*10.9*	...	36.8
240	233.0	93.5	96.5	78.7	81.2	240	239.5	*11.3*	...	37.3
242	235.0	93.9	96.7	78.9	81.4	242	241.5	*11.7*	...	37.7
244	237.0	94.3	97.0	79.2	81.6	244	243.5	*12.1*	...	38.2
246	239.1	94.6	97.3	79.4	81.8	246	245.5	*12.4*	*14.6*	38.6
248	241.3	95.0	97.8	79.7	82.0	248	247.5	*12.8*	*14.9*	39.1
250	243.5	95.4	98.1	79.9	82.2	250	249.5	*13.2*	*15.2*	39.5
252	245.5	95.7	98.3	80.1	82.4	252	251.5	*13.6*	*15.6*	39.9
254	247.5	96.1	98.7	80.3	82.6	254	253.5	*13.9*	*16.0*	40.3
256	249.5	96.5	99.0	80.6	82.7	256	255.5	*14.3*	*16.5*	40.7
258	251.5	96.8	99.4	80.8	82.9	258	257.5	*14.6*	*16.9*	41.1
260	253.5	97.2	99.8	81.0	83.1	260	259.5	*15.0*	*17.3*	41.5
262	255.5	97.6	*100.2*	81.2	83.3	262	261.5	*15.4*	*17.7*	41.9
264	257.5	97.9	*100.5*	81.4	83.5	264	263.5	*15.7*	*18.1*	42.2
266	259.5	98.3	*100.8*	81.6	83.7	266	265.5	*16.1*	*18.4*	42.6
268	261.5	98.6	*101.2*	81.8	83.8	268	267.5	*16.4*	*18.8*	42.9
270	263.5	98.9	*101.5*	82.0	84.0	270	269.5	*16.8*	*19.2*	43.3

TABLE III.—*Continued.*

As-Rolled						After Precipitation Hardening at 600 F				
Diamond Pyramid Hardness		Rockwell "B" Hardness		Rockwell Superficial "30T" Hardness		Diamond Pyramid Hardness		Rockwell "C" Hardness		Rockwell Superficial "30N" Hardness
2½-kg load	5-kg load	Under 0.0320 to 0.0126 in., incl, thick	0.0320 in. and over thick	Under 0.0320 to 0.0126 in., incl, thick	0.0320 in. and over thick	2½-kg load	5-kg load	Under 0.0320 to 0.0126 in. incl, thick	0.0320 in. and over thick	0.0100 in. and over thick
272	265.6	99.3	*101.8*	82.2	84.2	272	271.5	*17.2*	*19.6*	43.6
274	267.9	99.6	*102.1*	82.4	84.3	274	273.5	*17.5*	20.0	43.9
276	270.0	100.0	*102.4*	82.7	84.5	276	275.5	*17.9*	20.3	44.3
278	272.0	*100.3*	*102.8*	82.9	84.6	278	277.5	*18.2*	20.7	44.6
280	274.0	*100.6*	*103.1*	83.1	84.8	280	279.5	*18.6*	21.1	44.9
282	276.2	*101.0*	*103.4*	83.3	85.0	282	281.8	*19.0*	21.5	45.2
284	278.4	*101.4*	*103.7*	83.5	85.2	284	285.2	*19.3*	21.9	45.5
286	279.6	*101.8*	*104.0*	83.7	85.4	286	287.5	*19.7*	22.2	45.8
...	...	...	...	...	...	288	289.9	20.0	22.6	46.1
...	...	...	...	...	...	290	291.0	20.4	23.0	46.4
...	...	...	...	...	...	292	293.0	20.7	23.4	46.7
...	...	...	...	...	...	294	295.0	21.1	23.7	47.0
...	...	...	...	...	...	296	297.0	21.4	24.1	47.3
...	...	...	...	...	...	298	299.0	21.8	24.4	47.6
...	...	...	...	...	...	300	301.1	22.1	24.8	47.9
...	...	...	...	...	...	302	303.3	22.4	25.1	48.2
...	...	...	...	...	...	304	305.6	22.7	25.5	48.5
...	...	...	...	...	...	306	307.8	23.1	25.8	48.7
...	...	...	...	...	...	308	310.0	23.4	26.2	49.0
...	...	...	...	...	...	310	312.0	23.7	26.5	49.3
...	...	...	...	...	...	312	314.0	24.0	26.8	49.6
...	...	...	...	...	...	314	316.0	24.4	27.1	49.8
...	...	...	...	...	...	316	318.0	24.7	27.5	50.1
...	...	...	...	...	...	318	320.0	25.1	27.8	50.3
...	...	...	...	...	...	320	322.0	25.4	28.1	50.6
...	...	...	...	...	...	322	324.0	25.7	28.4	50.9
...	...	...	...	...	...	324	326.0	26.0	28.7	51.1
...	...	...	...	...	...	326	328.0	26.4	29.1	51.4
...	...	...	...	...	...	328	330.0	26.7	29.4	51.6
...	...	...	...	...	...	330	332.0	27.0	29.7	51.9
...	...	...	...	...	...	332	334.0	27.3	30.0	52.2
...	...	...	...	...	...	334	336.0	27.6	30.3	52.4
...	...	...	...	...	...	336	338.0	27.8	30.6	52.7
...	...	...	...	...	...	338	340.0	28.1	30.9	52.9
...	...	...	...	...	...	340	342.0	28.4	31.2	53.2
...	...	...	...	...	...	342	344.0	28.7	31.5	53.4
...	...	...	...	...	...	344	346.0	29.0	31.8	53.7
...	...	...	...	...	...	346	348.0	29.2	32.1	53.9
...	...	...	...	...	...	348	350.0	29.5	32.4	54.2
...	...	...	...	...	...	350	351.9	29.8	32.7	54.4
...	...	...	...	...	...	352	353.8	30.1	33.0	54.7
...	...	...	...	...	...	354	355.7	30.3	33.2	54.9
...	...	...	...	...	...	356	357.6	30.6	33.5	55.2
...	...	...	...	...	...	358	359.5	30.8	33.7	55.4
...	...	...	...	...	...	360	361.5	31.1	34.0	55.7
...	...	...	...	...	...	362	363.5	31.4	34.3	56.0
...	...	...	...	...	...	364	365.5	31.7	34.6	56.2
...	...	...	...	...	...	366	367.5	31.9	34.9	56.5
...	...	...	...	...	...	368	369.5	32.2	35.2	56.7
...	...	...	...	...	...	370	371.5	32.5	35.5	57.0

(Continued on p. 238.)

TABLE III.—*Concluded.*

As-Rolled						After Precipitation Hardening at 600 F				
Diamond Pyramid Hardness		Rockwell "B" Hardness		Rockwell Superficial "30T" Hardness		Diamond Pyramid Hardness		Rockwell "C" Hardness		Rockwell Superficial "30N" Hardness
2½-kg load	5-kg load	Under 0.0320 to 0.0126 in., incl, thick	0.0320 in. and over thick	Under 0.0320 to 0.0126 in., incl, thick	0.0320 in. and over thick	2½-kg load	5-kg load	Under 0.0320 to 0.0126 in., incl, thick	0.0320 in. and over thick	0.0100 in. and over thick
...	...	...	...	...	...	372	373.5	32.8	35.8	57.3
...	...	...	...	...	...	374	375.5	33.1	36.1	57.6
...	...	...	...	...	...	376	377.5	33.3	36.3	57.9
...	...	...	...	...	...	378	379.5	33.6	36.6	58.2
...	...	...	...	...	...	380	381.7	33.9	36.9	58.5
...	...	...	...	...	...	382	383.9	34.2	37.2	58.8
...	...	...	...	...	...	384	386.1	34.5	37.5	59.1
...	...	...	...	...	...	386	388.3	34.8	37.8	59.4
...	...	...	...	...	...	388	390.5	35.1	38.1	59.7
...	...	...	...	...	...	390	392.6	35.4	38.4	60.0
...	...	...	...	...	...	392	394.6	35.7	38.7	60.3
...	...	...	...	...	...	394	396.7	36.0	39.0	60.6
...	...	...	...	...	...	396	398.8	36.2	40.2	60.8
...	...	...	...	...	...	398	400.9	36.5	40.5	61.1
...	...	...	...	...	...	400	403.0	36.8	39.8	61.4

[a] Italicized values are given for information only. Rockwell hardness tests in this range (above "B" 100 and below "C" 20) are not recommended.

4. The Rockwell B scale was found suitable for testing as-rolled material 0.030 in. and over in thickness; the 30T scale proved suitable for such material 0.010 in. and over in thickness.

5. The Rockwell C scale was found suitable for testing precipitation hardened material 0.030 in. and over in thickness, whereas the 30N scale is applicable to such material 0.010 in. and over in thickness.

6. The best discrimination in the hardness - tensile strength relationship was obtained with the diamond pyramid hardness test.

Test Data:

On the basis of these findings, a new series of tests was undertaken in which all cooperating laboratories made their hardness determinations on the same set of tension specimens. Before any hardness readings were taken, the machines were first calibrated against a set of standard blocks. Finally, after all hardness readings had been taken, the tension specimens were tested by one of the cooperating laboratories. In this final series of tests, the various hardness measurements were made by the Riverside Metal Co., the General Electric Co., the International Business Machines Corp., Frankford Arsenal, and the Bell Telephone Laboratories, Inc. The latter also made the tension tests.

The second series of tests was confined to a study of the relationship between tensile strength and hardness for the diamond pyramid penetrator, the Rockwell B and C scales, and the Rockwell superficial 30T and 30N scales. Since these hardness readings were far more consistent than the previous test results, the readings were averaged and the resulting hardness values plotted against the tensile strength as shown in Figs. 1 and 2. (To facilitate the development of hardness conversions based upon groupings of different thicknesses than that selected by the Task Group, a summary of the original hardness-tensile strength data is given in Table II.) The best smooth curves showing the hardness-tensile strength relationship were drawn through the various points, and these curves were then used in compiling the hardness conversion values listed in Table III.

Preparation of Hardness Conversion Chart:

In preparing the hardness conversion chart for copper-beryllium alloy strip, the tensile strengths corresponding to each even diamond pyramid hardness number from 92 to 400 ($2\frac{1}{2}$-kg load) were read from Figs. 1 and 2. The diamond pyramid hardness (5-kg load), Rockwell B and Rockwell superficial 30T hardness values corresponding to these same tensile strength values were then read from Fig. 1 for the as-rolled copper-beryllium alloy strip; the diamond pyramid (5-kg load), Rockwell C and Rockwell superficial 30N hardness values were taken from Fig. 2 for the precipitation hardened material.

Use of Hardness Conversion Data:

The values listed in Table III are recommended for use in converting the results of one form of hardness test on copper-beryllium alloy strip to another only when the specific test procedures and precautions outlined in the Standard Methods of Test for Rockwell Hardness and Rockwell Superficial Hardness of Metallic Materials (E 18 - 42),[4] scales B, C, 30T, and 30N and the Tentative Method of Test for Diamond Pyramid Hardness of Metallic Materials (E 92 - 52 T),[5] are followed.

It is recognized that an anvil effect is present in many of the hardness tests covered by these conversions. However, approximate results, as given in Table III, will be obtained when the thickness limits indicated therein are observed. These conversion values are applicable only in the case of hardness test results obtained on flat specimens of copper-beryllium alloy strip that, it is assumed, has a reasonable uniformity of hardness between the surface and the center of the material. Lack of such uniformity will lead to deviations such as those observed between the diamond pyramid hardness numbers taken with the $2\frac{1}{2}$- and the 5-kg loads. For any material that has been given a light rolling after annealing, the diamond pyramid and Rockwell hardness conversion values may not be valid.

Acknowledgment:

The author is indebted to the various members of his Task Group for their cooperation in the basic testing program which made possible the preparation of this hardness conversion chart. The willingness of the General Electric Co., the International Business Machines Corp., the Sperry Gyroscope Co., the United States Department of the Army (Frankford Arsenal), the Riverside Metal Co., and the Bell Telephone Laboratories, Inc., to permit their representatives on ASTM Committee B-5 to carry out these hardness studies is appreciated. The Task Group is particularly indebted to the Riverside Metal Company for the preparation of the material and the test specimens, to Messrs. J. P. Guerard and J. W. Nalencz of the Bell Telephone Laboratories, Inc., for making the tension tests and to Miss A. V. Jastram and Miss Elsa Kerner of the same organization for the preparation of the various figures upon which the conversion chart is based.

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[4] 1952 Book of ASTM Standards, Part 2, p. 1238.

[5] 1952 Book of ASTM Standards, Part 2, p. 1293.

DISCUSSION

Mr. F. S. Stickney (*presented in written form*).[1]—A large percentage of the copper-beryllium strip sold under ASTM Specification B 194[2] is used for making springs. As a representative of the spring making industry, I believe it is reasonable to say that the industry wants better copper-beryllium strip, and better tools and methods for measuring the quality of that strip. The spring maker must generally satisfy the design engineer who specifies the performance of the spring. There is, to the best of my knowledge, no nationally recognized specification for the strength or hardness of copper-beryllium springs. Many designers therefore turn to Specification B 194 as the nearest specification available. A great many of the drawings for copper-beryllium springs call for hardness figures taken from this specification, whether or not these figures are suitable for the particular spring application.

Tensile strength is of little value in measuring the quality of a finished spring. Most springs are too small for a tension test. So the spring manufacturer must sell his product mostly on the basis of a hardness test.

Both the producer and purchaser of copper-beryllium springs for purposes of quality control need hardness testers which are accurate and practical. The test should preferably be nondestructive, but it must also be fast, because thousands of determinations must be made daily in some plants. While the DPH system of hardness testing may be an excellent tool in the laboratory, there are many producers and users of copper-beryllium springs who consider the Rockwell superficial tester more practical for daily production testing. A fast method of testing, without necessity for highly skilled technicians, is definitely needed.

Thickness of Strip:

We have made an analysis of our usage of copper-beryllium strip with respect to thickness. We consume this strip in all of the popular gages from 0.001 to 0.094.

The following table is based on the area of strip consumed, since inspection problems are more nearly proportional to area than to weight:

Gage	Per cent of Total Consumption
Under 0.005	19.7
Under 0.010	57.2
Under 0.015	93.6
Under 0.020	96.6
Under 0.025	98.7
0.025 and over	1.3

If our experience is typical of the copper-beryllium spring industry, and we have many reasons for believing that it is, it appears that the spring industry needs methods of measuring hardness for the thinner gages much more than it does for the thicker gages. Contrary to this need, the proposed hardness conversion table shows no tests on metal thinner than 0.010. It shows no data whatever for the Rockwell 15N scale which has been found very practical, reasonably accurate, and is in use for metal down to 0.005 in. thickness.

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[1] Chief Engineer, Instrument Specialties Co., Inc., Little Falls, N. J.

[2] Specification for Copper-Beryllium Alloy Plate, Sheet, Strip, and Rolled Bar (B 194 – 52), 1955 Book of ASTM Standards, Part 2, p. 330.

Quality of Samples Tested:

Referring in particular to the curves of Fig. 2 and the data of Table II, we note a peculiarity of the samples tested which may have a serious effect on users of thin strip. Specification B 194 is of greatest usefulness in establishing the minimum physical properties for hardened copper-beryllium strip in various conditions of tempers. It appears that many of the tests upon which the proposed conversion table is based were made on strip which, after hardening, did not conform to Specification B 194-46aT. This is particularly true of the thinner gages.

Stock Thickness, in.	Condition	Minimum Tensile Strength for Acceptable Metal per B 194-46a T, psi	Tensile Strength of Samples Used for Tests Reported, psi
0.010	Annealed	150 000	110 000
0.0126	Annealed	150 000	124 000
0.016	Annealed	150 000	115 000
0.020	Annealed	150 000	120 000
0.025	Annealed	150 000	126 000
0.032	Annealed	150 000	136 000
0.040	Annealed	150 000	172 000 OK
0.050	Annealed	150 000	172 000 OK
0.064	Annealed	150 000	172 000 OK

The above table shows only annealed material hardened per Specification B 194-46a T. The $\frac{1}{4}$ H, $\frac{1}{2}$ H, and H samples of all gages under 0.040 in. are also much below specified hardness, much lower than can be accounted for by hardening for 3 hr at 600 F. It appears, therefore, that all of the samples tested under 0.040 in. thickness were badly deficient in response to hardening heat treatment. This deficiency could be caused by: (*a*) insufficient total percentage of beryllium, (*b*) improper solution anneal with resulting unavailability of beryllium for hardening, (*c*) excessive beta constituent, (*d*) excessive grain boundary constituent, and (*e*) departure from good ratio of grain size to stock thickness.

We feel that any authoritative hardness conversion table should be based on data which include tests on material which conforms to Specification B 194-52 in the thin gages.

In the curves for Rockwell C and Rockwell 30N (Fig. 2) there is a noticeable scattering of points, apparently from anvil effect. We feel that desirable accuracy is lost by attempting to plot an average line through these scattered points. For example, the curve for Rockwell 30N is well above most of the points for gages 0.016 in. and under. It is doubtful if the mills would be able to produce thin materials in accordance with the curve shown. A family of curves for different stock thicknesses would be a better answer when anvil effect is a factor.

Constructive Suggestions:

Before making the Hardness Conversion Table an official part of Specifications B 194, the testing program should be continued along the following lines: (*a*) comparative determinations should be made with gages down to and including 0.005 in., (*b*) determinations should be made from material capable of good hardenability, in accordance with B 194-52, (*c*) the usefulness of the Rockwell 15N scale should be investigated with respect to thin material of good hardenability, and (*d*) since anvil effect appears in much of the data on thin material, we suggest that final results be expressed as a function of stock thickness.

MR. G. R. GOHN (*author*).—Mr. Stickney has restated quite concisely the aims of all materials engineers whether they represent consumer or producer interests, namely, the procurement of better raw materials and the development of better tools and instruments for measuring the quality of those materials.

Unfortunately, in his zeal to accomplish these very worthy aims, Mr. Stickney has proposed the use of an excellent testing machine—the Rockwell superficial hardness tester—for specification and quality control in an area in which it has been demonstrated that this machine cannot be satisfactorily used. For example, the work of the Task Group, which is summarized on page 231 of this paper, showed that material ranging in thickness from 0.010 to 0.064 in., when precipitation-hardened at 600 F to the tensile strength values prescribed in Specification B 194 - 46a T, had an average spread in hardness of only 3.3 Rockwell numbers (15N scale) between the heat-treated, annealed material (condition AT material having a minimum tensile strength ranging from 150,000 to 170,600 psi compared to the then specified minimum value of 150,000 psi) and heat-treated, extra hard temper material having a minimum tensile strength ranging from 189,600 to 194,600 psi. Compared to this spread for the entire range of tempers tested, spreads of more than 10 hardness numbers were observed between different cooperating laboratories when using the 15N scale.

Frequently, the lowest Rockwell 15N reading was associated with the highest tensile strength. Also spreads of approximately equal magnitude were observed in both heavy and light gage material. Furthermore, this 3.3 spread in hardness is less than the permissible spread of 4 numbers allowed by the ASTM Standard Methods of Test for Rockwell Hardness and Rockwell Superficial Hardness of Metallic Materials (E 18)[3] for machines in good operating condition. Thus it can be seen that the 15N hardness scale fails to discriminate among the various tempers and should not be used as an inspection tool for the material covered in this paper.

The objections cited to the use of the 15N scale for the hardness testing of copper-beryllium strip do not apply to the diamond pyramid hardness test. With machines such as those available today, this test is scarcely more time consuming than the more conventional hardness tests and, in the author's opinion, can readily be developed for use in testing material below 0.010 in. in thickness.

The reader should not confuse the two problems cited—namely, the inspection of the copper-beryllium strip to ensure conformance to the requirements of ASTM Specification B 194 and the quality control of parts made therefrom. The first is now covered in Specification B 194; the latter at present can only be a matter of agreement between the supplier of springs or parts made from the copper-beryllium strip and the purchaser until a new specification is written covering springs.

There is definitely a need for a nondestructive test for thin sheet and strip material. However, such a test should be one which discriminates among the various tempers, is commercially available, and one which can be readily reproduced in different laboratories. This is of course outside the scope of the author's paper as is the development of hardness conversion values for material less than 0.010 in. in thickness—the thinnest material for which hardness values are specified in B 194.

All material tested by the Task Group conformed to the requirements of ASTM Specification B 194 - 46a T. It had a beryllium content falling within the range of 1.90 to 2.15 per cent, a total nickel plus cobalt plus iron content within the range of 0.15 to 0.50 per cent and met the minimum requirement for nickel plus additive elements.

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[3] 1955 Book of ASTM Standards, Part 2, p. 1285.

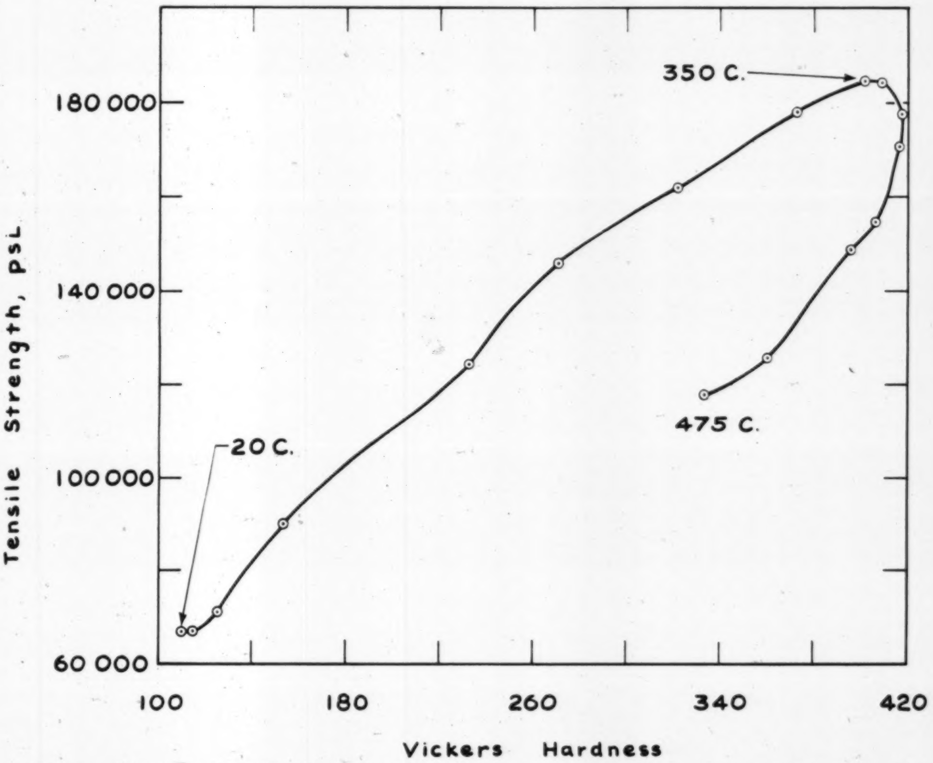

FIG. 3.—Hardness-Tensile Strength Relationship Resulting from Aging Solution-Treated Copper-Beryllium Strip for 1 hr at Various Temperatures. (Diamond pyramid hardness—$2\frac{1}{2}$-kg load.)

Originally, all specimens were heat treated to meet the specified tensile strength values which at that time were:

Condition	Minimum Tensile Strength, psi
AT	150 000
$\frac{1}{4}$ HT	160 000
$\frac{1}{2}$ HT	170 000
HT	180 000

The material definitely had the correct beryllium content, and was properly heat treated in the solution anneal as indicated by the response to precipitation hardening at 600 F. Whether or not there was excessive beta constituent, excessive grain boundary constituent, or the incorrect ratio between grain size and thickness is purely speculative and cannot be established at this late date. However, it can be stated that all material was prepared by one of the two commercial producers of copper-beryllium alloy strip under the personal supervision of the members of the technical staff; hence it can be assumed that every precaution was taken to prevent the use of abnormal material for these studies.

In the second series of tests, which are the basis of the present conversion table, the same basic material was used with slight deviations in heat treatment to produce strip material having a wider range of tensile strengths. This was necessary in order to develop conversion values over the range covered by the tensile strengths specified in ASTM Specification B 194-46a T.

The breakdown in thickness values used by the author is that recommended by the Task Group and adopted by Committee B-5. More precise conversion values can be obtained by taking the original data presented in Table II of this paper and plotting a series of curves showing the relationship between tensile strength and hardness for each thickness if this is deemed desirable.

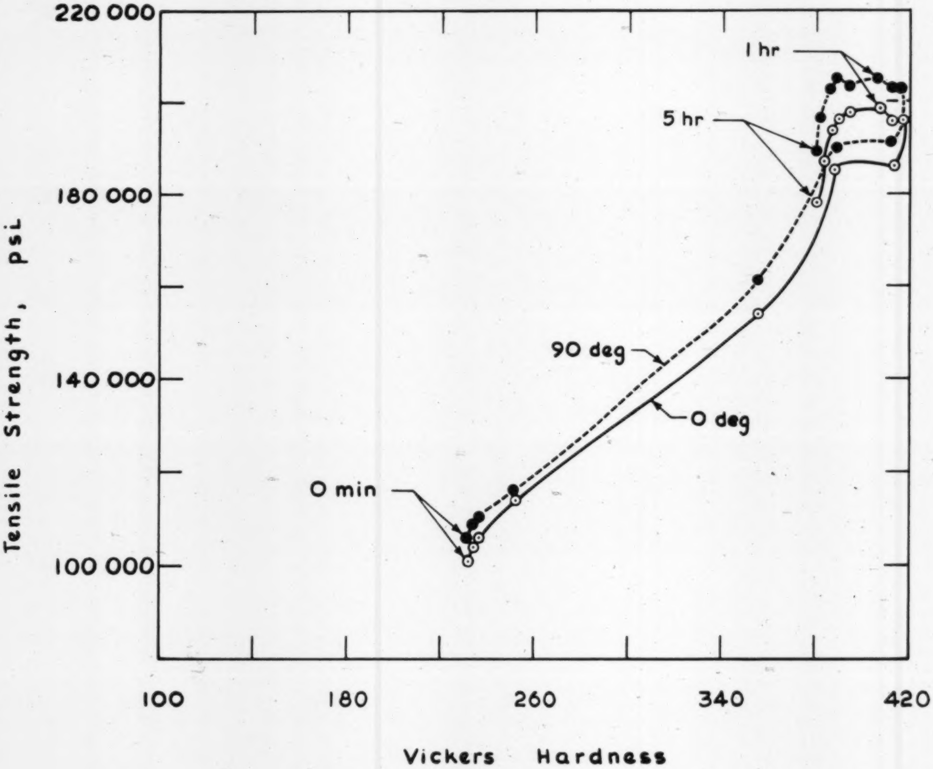

FIG. 4.—Hardness-Tensile Strength Relationship Resulting from Aging Hard-Rolled Copper-Beryllium Strip at 680 F for Various Times. (Diamond pyramid hardness—2½-kg load, tension tests at 0 deg and 90 deg with respect to rolling direction.)

MR. J. T. RICHARDS[4] (*presented in written form*).—This paper is of considerable interest, since we have attempted for several years to develop a workable hardness conversion table for copper-beryllium strip. Unfortunately, our work indicates that hardness conversion is dependent upon structure. Structure, in turn, is dependent upon the degree of cold work as well as precipitation-hardening time and temperature.

Several typical cases are shown in the accompanying Figs. 3 and 4. In Fig. 3, note that at a hardness level of Vickers

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[4] Chief Engineer, Penn Precision Products, Inc., Reading, Pa.

340 the tensile strength may be 167,000 psi or 119,000 psi, depending upon whether the strip is underaged or overaged.

This seemingly anomalous condition perhaps results from the presence of excessive grain boundary precipitate which accompanies overaging. It has been shown[5] that the Vickers hardness of a grain may vary from 390 in the center to 280 at the boundary. This softness at the boundary is also an indication of low strength, so that the greater sensitivity of the tension test will reflect this weakness whereas the averaging characteristic of the hardness test will probably be largely influenced by the hardness of the grain center.

Figure 4 illustrates the effect of preferred orientation upon hardness conversion. Where greater directionality is exhibited, the problem of conversion will become even more difficult.

Although the practical aspects of hardness conversion are apparent, it would appear that additional work is needed to clarify this difficult situation.

MR. GOHN.—I think Mr. Richards' comments on the effect of structure on hardness warrant further investigation. It is a study which would appear to offer considerable promise of useful information. I also think that the importance of Mr. Richards' last remarks should be further emphasized.

Committee B-5 is pretty well agreed that hardness is not an entirely satisfactory substitute for the tension test. The tensile strength test itself is not a measure of the property or properties of general engineering interest. It is merely a device for measuring the general level of quality in a given material. It is used because the tensile strength does reflect differences in composition or fabrication whereas the yield strength, fatigue strength, or creep strength in which we are really interested cannot readily be measured and hence are unsuitable for inspection purposes.

However, because the tension test is itself an expensive and time consuming one, nondestructive hardness tests are frequently used as a substitute. Nevertheless the limitations of the hardness test are implicit in the fact that Committee B-5 is on record, in practically all of its specifications except two, that the hardness test shall be used for information only, and that the tension test, which is by custom and long usage more dependable and more reliable, shall be the ultimate test for inspecting materials.

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[5] John T. Richards, "A Review of Beryllium and Beryllium Alloys," *Journal of Metals*, Vol. 3, May, 1951, pp. 379–386.

REPORT OF COMMITTEE B-6

ON

DIE-CAST METALS AND ALLOYS*

Committee B-6 held two meetings during the year: one in Chicago, Ill., on June 16, 1954, and one in Cincinnati, Ohio, on February 2, 1955.

There was a balance of $2837.56 in the funds of Committee B-6 as of December 10, 1954.

At the present time, the committee consists of 95 members, of whom 46 are classified as producers, 25 as consumers, and 24 as general interest members.

ACTIVITIES OF SUBCOMMITTEES

Subcommittee I on Aluminum-Base Die-Casting Alloys (E. V. Blackmun, chairman) reports that new mechanical properties have been determined for Alloys SC84A and SC84B and that the task group is now determining the properties for Alloys SG100A and SG100B. It is planned to place the new data for the aluminum alloys in the Appendix of Specification B 85 as soon as letter ballot approval is obtained. An appropriate footnote will be included in the specification to explain that data for the remaining alloys will be determined and added to the Appendix from time to time.

A study has been completed in which the number of decimal places for the impurities in the chemical requirements table in Specification B 85 will be changed to conform with the B 179 ingot specifications following receipt of letter ballot approval.

A table of die-casting and other characteristics for the aluminum alloys has been prepared for inclusion in the Appendix of Specification B 85, subject to letter ballot approval.

Amendment No. 2 in Federal Specification QQ-A-591a has corrected the confusion that resulted between Federal Alloy 13 and Aluminum Alloy 13 (SG100A). The new Federal number is 12A.

Subcommittee II on Zinc-Base Die-Casting Alloys (A. E. Weiss, chairman) is currently seeking letter ballot approval on the inclusion of the following footnote which refers to "Zinc-Remainder" in Table I of Specification B 86: "Analysis shall not regularly be made for elements other than those in Table I. If elements other than those in Table I are found by the purchaser in the course of regular analysis, they shall not exceed the following limits: chromium, 0.02 per cent, nickel, 0.02 per cent, manganese, 0.05 per cent, silicon, 0.035 per cent, others, 0.001 per cent."

A task group is currently recording the evolution of the present zinc die-casting alloys and describing their relative differences.

Subcommittee V on Exposure and Corrosion Tests (D. H. Kleppinger, chairman).—At the spring, 1952, meeting it was voted to start exposure tests to determine the effect of zinc on the corrosion resistance of the SC84A alloy. These tests were to be performed utilizing test bars with controlled amounts of zinc which had been left over from a previous program where the effect of zinc on mechanical properties had been evaluated. The test bars were made by three producers: the Precision Castings Co., the Stewart Warner Co., and the Bell Telephone Laboratories, which for convenience in reporting data were assigned coded letters A, B, and C (not respectively). The bars were all made from a single master heat of metal produced by the Apex Smelting Co. in five lots, each lot having a different zinc content. The zinc contents investigated were 0.25, 0.50, 1.0, 1.5, and 2.0 per cent, which were coded 1, 2, 3, 4, and 5, respectively. One producer (B) made bars with approximately 3.0 per cent zinc which was coded 6.

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* Presented at the Fifty-eighth Annual Meeting of the Society, June 26–July 1, 1955.

The test bars were tested in the as-cast condition, the results being shown in Table I. It must be pointed out that producers A and C did not radiograph their test bars, whereas producer B did.

Since the mechanical tests showed that a number of the test bars of producers A and C were unsound, the remaining test bars made for the program were radiographed and hermetically sealed and stored at Frankford Arsenal.

These bars were taken from storage in April, 1953, and were sent to three test sites for exposure. The test sites and times for exposure were: New York Port Authority Roof for 1, 3, 6, and 12 yr; Kure Beach 80-ft site for 1 and 3 yr,

TABLE I.—SUMMARY OF MECHANICAL TEST DATA OF SC84A ALLOY TEST BARS.

	Yield Strength, psi				Tensile Strength, psi				Elongation, per cent			
	Lab X	Lab Y	Lab Z	Average	Lab X	Lab Y	Lab Z	Average	Lab X	Lab Y	Lab Z	Average
Producer A:												
A_1	19 500	19 800	19 000	19 400	41 100	40 600	40 100	40 600	3.4	3.1	3.3	3.3
A_2	18 700	19 200	18 400	18 800	39 200	39 800	40 900	40 000	3.3	3.4	3.6	3.4
A_3	18 800	18 400	18 000	18 400	39 400	39 800	39 400	39 500	3.0	3.3	3.0	3.1
A_4	18 900	20 900	18 100	19 300	42 100	43 200	40 200	41 800	4.5	4.0	3.1	3.0
A_5	19 500	20 100	19 200	19 600	41 100	43 900	42 500	42 500	3.8	4.0	3.6	3.8
Producer B:												
B_1	19 900	21 100	19 400	20 100	43 100	42 200	44 600	43 300	3.3	3.6	4.4	3.8
B_2	18 800	20 500	19 100	19 500	43 400	42 500	44 500	43 500	3.8	3.8	4.5	4.0
B_3	19 400	20 800	19 200	19 800	43 900	43 000	44 100	43 700	4.1	4.0	4.5	4.2
B_4	19 600	21 000	19 000	19 900	42 900	42 400	43 200	42 800	3.7	3.3	4.2	3.7
B_5	19 000	20 600	19 200	19 600	43 100	42 900	43 700	43 200	4.0	3.7	4.5	4.1
Producer C:												
C_1	21 000	21 800	22 600	21 800	40 400	40 400	42 900	41 200	3.1	3.2	3.4	3.2
C_2	21 900	22 100	21 700	21 900	42 200	40 200	41 000	41 100	3.4	2.9	3.0	3.1
C_3	21 200	22 900	21 900	22 000	42 300	41 600	43 800	42 600	4.1	3.0	4.2	3.8
C_4	20 900	22 100	20 900	21 300	41 400	40 200	43 200	41 600	3.9	3.8	4.1	3.9
C_5	20 700	22 000	21 200	21 300	42 500	41 000	42 700	42 000	4.2	3.9	3.9	4.0

Zinc, per cent	Average Yield Strength, psi	Average Tensile Strength, psi	Elongation, per cent
0.25	20 400	41 700	3.4
0.50	20 100	41 500	3.5
1.0	20 100	41 900	3.7
1.5	20 200	42 100	3.8
2.0	20 200	42 600	4.0
3.0	20 200	41 800	3.9

TABLE II.—ONE-YEAR OUTDOOR EXPOSURE ON PORT AUTHORITY BUILDING, NEW YORK, N. Y.

Specimen	Frankford Arsenal			Bell Telephone Labs.			American Smelting and Refining Co.			Average		
	Tensile Strength	Yield Strength	Elongation	Tensile Strength	Yield Strength	Elongation	Tensile Strength	Yield Strength	Elongation	Tensile Strength	Yield Strength	Elongation
A_1—Zn, 0.25%........	42 000	22 300	2	42 300	22 800	3	45 500	22 900	3	42 500	22 500	2.7
	43 900	22 300	2.9	39 000	22 200	...						
B_1—Zn, 0.25%........	45 500	23 400	3	40 800	...	3	43 700	23 800	3	43 700	23 500	3.1
				43 300	23 200	3	45 000	23 400	3.5			
C_1—Zn, 0.25%........	40 200	24 700	2.2	42 000	25 700	...	41 800	24 400	3	41 300	24 800	2.9
				42 100	25 300	3.5	40 400	24 000	3			
Grand Average.........										42 500	23 600	2.9
A_2—Zn, 0.50%........	43 500	23 700	2.3	38 400	21 800	3.0	39 900	22 200	3.0	40 200	22 900	2.9
				38 100	22 400	3.0	41 200	24 200	3.0			
B_2—Zn, 0.50%........	43 700	22 200	3.0	42 500	23 000	3	43 000	23 000	3	43 200	22 900	2.9
	43 000	22 500	2.6				43 800	23 600	3			
C_2—Zn, 0.50%........	42 800	24 300	2.5	38 700	25 100	2.5	37 200	22 800	2.5	39 000	24 500	2.5
	39 400	25 100	2.9				41 400	25 400	2			
Grand Average.........										40 800	23 400	2.8
B_3—Zn, 1.0%.........	43 000	22 500	2.6	43 100	22 200	4.0	41 500	22 600	3.0	42 700	22 600	3.1
	42 500	23 200	2.6	42 800	22 600	...						
C_3—Zn, 1.0%.........	43 800	24 300	3.3	41 300	24 000	3.5	40 700	24 600	3.0	42 100	24 600	3.0
	42 800	25 700	2.4	41 800	24 400	3.0						
Grand Average.........										42 400	23 600	3.1
A_4—Zn, 1.5%.........	41 800	22 200	2.4	42 600	22 800	3	44 200	23 700	3	41 900	23 100	2.7
	41 400	23 300	2.8				30 400	23 300	2.5			
B_4—Zn, 1.5%.........	40 600	22 700	2.7	42 300	...	4.0	41 900	23 400	3	42 000	23 000	3.2
				43 100	23 000	...	42 000	22 800	3			
C_4—Zn, 1.5%.........	43 900	23 400	3.8	43 200	24 200	3.5	40 400	24 400	3	42 000	24 100	3.2
				43 300	24 400	3.5	39 000	24 200	2			
Grand Average.........										42 000	23 400	3.0
A_5—Zn, 2.0%.........	42 300	23 300	2.8	36 100	21 600	3.0	39 900	23 300	3	40 300	22 600	2.9
	41 900	22 600	2.6	41 200	22 000	...						
B_5—Zn, 2.0%.........	42 700	22 900	3.0	42 100	23 000	4.0	43 000	23 400	...	42 500	23 000	3.3
	43 100	22 500	3.2				41 700	23 000	3			
C_5—Zn, 2.0%.........	43 800	24 200	2.4	42 900	25 300	3.5	40 400	23 600	2	42 200	23 900	2.8
	43 000	23 800	3.2				41 000	22 800	3			
Grand Average.........										41 700	23 200	3.0
B_6—Zn, 3.0%.........	42 300	22 700	2.7	42 100	23 200	3.5	41 700	26 200	3	42 500	23 900	3.1
	43 400	23 800	2.7	43 000	23 400	3.5						
Grand Average.........										42 500	23 900	3.1

TABLE III.—ONE-YEAR OUTDOOR EXPOSURE AT KURE BEACH 80-FT SITE.

Specimen	Frankford Arsenal			Bell Telephone Labs.			American Smelting and Refining Co.			Average		
	Tensile Strength	Yield Strength	Elongation	Tensile Strength	Yield Strength	Elongation	Tensile Strength	Yield Strength	Elongation	Tensile Strength	Yield Strength	Elongation
A_1	36 100	21 600	2.0	35 300	21 800	2	Not	23 600	2	36 300	22 500	1.9
	37 900	23 500	1.7	36 000	22 000	2	reported					
B_1	39 800	24 500	1.3	38 600	23 200	2	38 800	24 300	2	38 200	23 900	1.7
	38 400	23 200	1.4				35 600	24 100	2			
C_1	37 500	23 900	1.6	37 200	25 000	2	39 300	23 400	2	37 700	24 100	2.0
	37 300	24 200	2.2				37 000	24 100	2			
							Grand Average			37 400	23 500	1.9
A_2	33 500	20 600	1.7	35 100	22 200	2	34 100	22 000	2	35 100	22 200	1.9
				37 600	23 400	...	35 000	22 800	2			
B_2	33 300	20 700	1.3	38 600	22 300	...	35 600	23 200	2	36 800	22 200	1.8
	38 900	22 200	2.0	37 800	22 500	...						
C_2	36 400	24 900	1.3	38 000	25 300	2	35 400	24 100	2	36 600	24 400	1.9
	36 500	23 900	1.8	36 700	24 000	2						
							Grand Average			36 200	22 900	1.9
A_3	36 800	21 500	1.3	37 400	22 000	2	30 000	21 800	1	34 600	21 600	1.6
	31 400	20 200	1.8				37 400	22 600	2			
B_3	36 500	22 200	2.0	37 300	23 800	...	36 000	23 700	2	27 100	23 100	2.0
				38 000	23 000	2	37 600	22 600	2			
C_3	38 300	24 400	1.4	36 100	25 400	2	35 900	23 200	2	36 500	23 900	1.8
				35 900	23 900	1.5	36 100	22 800	2			
							Grand Average			36 100	22 900	1.8
A_4	36 700	22 500	1.0	35 200	23 200	2	33 600	22 200	2	35 400	22 500	1.7
	36 200	21 600	1.3	35 300	23 100	2						
B_4	36 800	22 200	1.5	38 400	23 100	2	38 000	23 500	2	27 600	22 800	1.9
	37 100	22 000	1.9				37 600	23 200	2			
C_4	38 000	24 200	1.8	34 200	23 600	2	36 000	24 100	2	35 500	24 000	1.8
	36 400	23 900	1.4				32 800	24 400	2			
							Grand Average			36 200	23 100	1.8
A_5	41 000	24 500	2.4	37 300	22 900	2	37 300	23 600	2	38 200	23 700	2.1
				38 500	23 000	2	37 000	24 400	2			
B_5	37 300	22 400	2.0	35 200	22 900	2	37 400	23 700	2.5	36 200	22 700	2.1
	33 300	21 700	1.9	37 800	23 000	2						
C_5	35 300	22 900	1.7	36 700	23 100	2	34 200	24 400	2.0	36 300	23 600	1.9
	38 000	23 900	2.0	37 200	23 800	2						
							Grand Average			36 900	23 300	2.0
B_6	34 700	22 900	1.6	37 600	23 200	2	31 600	23 500	2	35 300	23 300	1.9
										35 300	23 300	1.9

TABLE IV.—ONE-YEAR OUTDOOR EXPOSURE AT KURE BEACH 800-FT SITE.

Specimen	Frankford Arsenal			Bell Telephone Labs.			American Smelting and Refining Co.			Average		
	Tensile Strength	Yield Strength	Elongation	Tensile Strength	Yield Strength	Elongation	Tensile Strength	Yield Strength	Elongation	Tensile Strength	Yield Strength	Elongation
B_1	38 900	21 700	1.8	39 000	22 700	2.5	39 000	23 300	2	38 600	22 500	1.9
	39 400	23 500	1.3				36 800	21 500	2			
C_1	39 200	23 700	1.2	38 700	24 400	2	39 100	24 200	3	38 400	23 900	2.1
	38 700	23 400	1.9				36 200	23 700	2.5			
Grand Average										38 500	23 200	2.0
B_2	38 900	21 800	2.7	39 100	23 000	2	37 900	21 500	2	38 000	22 300	2.1
	35 400	22 400	1.7	38 600	22 600	2						
C_2	38 900	23 800	1.6	39 800	23 600	...	34 400	25 200	1	37 900	23 900	1.7
	38 700	23 200	2.0	37 600	23 700	2						
Grand Average										38 000	23 100	1.9
B_3	39 800	22 200	2.8	37 800	22 800	2	37 000	21 500	2	37 300	22 600	2.1
				36 500	22 200	1.5	35 600	24 200	2			
C_3	36 700	23 200	1.9	36 700	23 500	2	35 200	26 200	2	35 800	24 200	2.1
				32 900	23 800	1.5	37 500	24 200	2			
Grand Average										36 600	23 400	2.1
B_4	37 400	22 200	1.7	36 500	24 100	2	37 400	23 800	2	37 700	22 800	2.0
	38 400	21 700	2.3				38 900	22 100	2			
C_4	37 700	21 900	1.5	37 000	23 400	2	37 000	24 100	2	37 000	23 000	2.0
	39 200	22 400	2.3				34 000	23 300	2			
Grand Average										37 400	22 900	2.0
A_5	37 600	22 500	1.8	34 900	...	1.5	37 200	22 800	2	36 100	22 800	1.9
				37 400	23 300	2.0	22 200	22 600	2			
B_5	37 400	22 200	1.4	38 800	22 700	2	37 000	23 500	2	37 600	22 600	1.8
	37 400	22 000	1.7	37 600	22 500	2						
C_5	35 600	23 000	1.8	38 300	24 300	2	36 200	23 300	2	36 800	23 500	1.8
	36 700	23 400	1.0	37 200	23 700	2						
Grand Average										36 800	23 000	1.8
B_6	35 400	21 800	1.7	37 800	23 600	2	35 700	23 600	2	36 500	23 200	1.9
				36 600	23 000	2	37 000	23 800	2			
Grand Average										36 500	23 200	1.9

Kure Beach 800-ft site for 1, 3, and 6 yr; and Battelle Memorial Inst. for 1, 3, 6, and 12 yr.

In April, 1954, the 1-yr test bars from New York City and Kure Beach were withdrawn. Through a series of misunderstandings, the bars which had been sent to Battelle had not been exposed. They will be returned for shelf aging or such other tests as might be desirable at a later date.

The test bars were tested by the Bell Telephone Laboratories, the American Smelting and Refining Co. Laboratories, and the Pitman-Dunn Laboratories of Frankford Arsenal. The test results are shown in Tables II, III, and IV.

No final conclusions were drawn from these data. In view of the small sample size and normal expected variation in die-cast tension bars, it would be impossible to state whether the effect of zinc is statistically significant. Normally the per cent elongation tests would assist in determining the significance of an apparent trend in tensile strength. In this case, because of the low values of elongation which are always difficult to determine, coupled with the presence of corrosion products to hinder determination, the accuracy and thus the significance of elongation data cannot be judged.

The committee has also removed aluminum alloy test bars IVa, V, and Va from the New York and Altoona test sites after 20 yr of exposure. Alloy IV was a 5 per cent silicon alloy and Alloy V was a 12 per cent silicon alloy. The "a" designation indicated the use of a high-purity aluminum.

The testing of these bars has been held up because black deposits and white corrosion products have made identification of the specimens a difficult task. This completes the exposure tests on these alloys.

Test specimens of aluminum alloys 218 (G8A) and 360 (SG100A) have been removed from the New York test site after 10 yr of exposure. This completes the exposure tests on these two alloys because the specimens at the Sandy Hook site were lost.

The subcommittee will undertake the compilation of all of the test data on alloys 218 and 360 so they can be recorded in a future report of this committee.

This report has been submitted to letter ballot of the committee, which consists of 95 members; 94 members returned their ballots, of whom 84 have voted affirmatively and 0 negatively.

Respectfully submitted on behalf of the committee,

W. BABINGTON,
Chairman.

GEORGE L. WERLEY,
Secretary.

REPORT OF COMMITTEE B-7

ON

LIGHT METALS AND ALLOYS, CAST AND WROUGHT*

Committee B-7 on Light Metals and Alloys held two meetings during the year: in Chicago, Ill., in June, 1954, and in Cincinnati, Ohio, in February, 1955.

The committee consists of 89 members, of whom 87 are voting members; 43 are classified as producers, 30 as consumers, and 16 as general interest members.

RECOMMENDATIONS ACCEPTED BY THE ADMINISTRATIVE COMMITTEE ON STANDARDS

Subsequent to the 1954 Annual Meeting, Committee B-7 presented to the Society through the Administrative Committee on Standards the following recommendations:

Tentative Recommended Practice for:

Temper Designation of Light Metals and Alloys, Cast and Wrought (**B 296 – 54 T**),

Revision of Tentative Specifications for:

Aluminum-Base Alloy Sand Castings (**B 26 – 52 T**),
Magnesium-Base Alloy Sand Castings (**B 80 – 53 T**),
Aluminum-Base Alloy Permanent Mold Castings (**B 108 – 52 T**),
Aluminum and Aluminum-Alloy Sheet and Plate for Pressure Vessel Applications (**B 178 – 53 T**),
Magnesium-Base Alloy Permanent Mold Castings (**B 199 – 51 T**),
Aluminum and Aluminum-Alloy Sheet and Plate (**B 209 – 53 T**),
Aluminum and Aluminum-Alloy Extruded Bars, Rods, and Shapes (**B 221 – 53 T**), and
Aluminum-Alloy Drawn Seamless Tubes for Condensers and Heat Exchangers (**B 234 – 53 T**).

The revisions of Tentative Specifications B 26 and B 108 were accepted by the Standards Committee on November 5, 1954; and the other recommendations were accepted on September 28, 1954. They all appear in the 1954 Supplement to Book of ASTM Standards, Part 2.

REVISION OF TENTATIVES

The committee recommends that the following nine tentative specifications be revised as set forth in the Appendix to this report:[1]

Tentative Specifications for:

Aluminum-Base Alloy Sand Castings (**B 26 – 54 T**),
Magnesium-Base Alloy Sand Castings (**B 80 – 54 T**),
Magnesium-Base Alloy Sheet (**B 90 – 51 T**),
Magnesium-Base Alloy Forgings (**B 91 – 54 T**),
Magnesium-Base Alloys in Ingot Form for Sand Castings, Die Castings, and Permanent Mold Castings (**B 93 – 52 T**),
Magnesium-Base Alloy Bars, Rods, and Shapes (**B 107 – 53 T**),
Aluminum-Base Alloy Permanent Mold Castings (**B 108 – 54 T**),
Magnesium-Base Alloy Permanent Mold Castings (**B 199 – 54 T**), and
Magnesium-Base Alloy Extruded Round Tubes (**B 217 – 53 T**).

ADOPTION OF TENTATIVE AS STANDARD WITH REVISIONS

The committee recommends that the Tentative Specifications for Aluminum

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* Presented at the Fifty-eighth Annual Meeting of the Society, June 26–July 1, 1955.

[1] See p. 256.

Bars for Electrical Purposes (Bus Bars) (B 236 – 52 T) be approved for reference to letter ballot of the Society for adoption as standard with revisions as set forth in the Appendix to this report.[2]

Adoption of Tentative as Standard Without Revision

The committee recommends that the Tentative Recommended Practice for Codification of Light Metals and Alloys, Cast and Wrought (**B 275 – 53 T**)[3] be approved for reference to letter ballot of the Society for adoption as standard without revision.

Revision of Standards, Immediate Adoption

The committee recommends revisions for immediate adoption of the following two standards as set forth in the Appendix to this report,[4] and accordingly asks for the necessary nine-tenths affirmative vote at the Annual Meeting in order that the revisions may be referred to letter ballot of the Society:

Standard Specifications for:

Magnesium Ingot and Stick for Remelting (**B 92 – 52**), and
Aluminum-Base Alloys in Ingot Form for Sand Castings, Die Castings, and Permanent Mold Castings (**B 179 – 53**).

Tentatives Continued Without Revision

The committee recommends that the Tentative Method of Measuring Thickness of Anodic Coatings on Aluminum by Means of the Filmeter (**B 244 – 49 T**) be continued as tentative without revision.

Reaffirmation of Standards

The committee recommends that the following five standards, which have stood for six or more years without revision, be reaffirmed:

Standard Specifications for:

Aluminum Ingots for Remelting (**B 24 – 46**),
Aluminum for Use in Iron and Steel Manufacture (**B 37 – 49**),

Standard Method of Test for:

Dielectric Strength of Anodically Coated Aluminum (**B 110 – 45**),
Sealing of Anodically Coated Aluminum (**B 136 – 45**), and
Weight of Coating on Anodically Coated Aluminum (**B 137 – 45**).

The recommendations in this report have been submitted to letter ballot of the committee, the results of which will be reported at the Annual Meeting.[5]

Activities of Subcommittees

Subcommittee I on Aluminum and Aluminum Alloy Ingots (R. A. Quadt, chairman) revised the Standard Specifications for Aluminum-Base Alloys in Ingot Form for Sand Castings, Die Castings, and Permanent Mold Castings (B 179 – 53), as set forth in the Appendix to this report, to revise the chemical requirements.

Subcommittee II on Aluminum Alloy Castings (D. L. Colwell, chairman) revised the Tentative Specifications for Aluminum-Base Alloy Sand Castings (B 26 – 54 T) and the Tentative Specifications for Aluminum-Base Alloy Permanent Mold Castings (B 108 – 54 T), as set forth in the Appendix to this report, to add a section on Basis of Purchase and to revise the chemical requirements.

Subcommittee III on Wrought Aluminum and Wrought Aluminum Alloys

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[2] The revised specifications appear in the 1955 Book of ASTM Standards, Part 2.

[3] 1953 Supplement to Book of ASTM Standards, Part 3.

[4] See p. 280.

[5] The letter ballot vote on these recommendations was favorable; the results of the vote are on record at ASTM Headquarters.

(P. V. Faragher, chairman) revised Tentative Specifications B 178 – 54 T, B 209 – 54 T, B 210 – 54 T, B 211 – 54 T, B 221 – 54 T, B 234 – 54 T, B 235 – 54 T, B 241 – 54 T, B 247 – 54 T, B 273 – 54 T, and B 274 – 54 T, as set forth in the Appendix to this report, to simplify some of the titles; to add AA alloy numbers for convenience in determining the commercial designations; to add a section on Basis of Purchase; to revise chemical composition limits, mechanical properties limits, and dimensional tolerances to coincide with industry standards; to make minor editorial changes, as well as to add alloy GR40A and five new tables of dimensional tolerances in B 209, and the -T4 temper of alloys GS11A and GS11C in B 234. The subcommittee also completely revised Tentative Specifications for Aluminum Bars for Electrical Purposes (Bus Bars) (B 236 – 52 T), as printed in its entirety in the Appendix to this report, to add the -H111 and -H112 tempers, to add edgewise bend requirements, to add requirements for finish, to revise dimensional tolerances, and to add an Appendix.

Subcommittee IV on Magnesium and Magnesium Alloys, Cast and Wrought (A. A. Moore, chairman) revised Tentative Specifications B 80 – 54 T, B 90 – 51 T, B 91 – 54 T, B 92 – 52, B 93 – 52 T, B 107 – 53 T, B 199 – 54 T, and B 217 – 53 T, as set forth in the Appendix to this report, to add a section on Basis of Purchase, as well as to increase the tensile requirements for alloys EK30A-T6 and EZ33A-T5 in B 80, to revise the permissible variations in dimensions in B 107 and B 217 to be the same as for aluminum in the revised B 221 and B 235, respectively, and to reduce the tensile strength requirement for alloy AZ31B in B 217 to agree with B 107.

Subcommittee V on Testing Light Metals (R. L. Templin, chairman) is continuing to investigate statistical sampling methods as applied to testing for mechanical properties and, in cooperation with Committee E-11 on Quality Control of Materials, is attempting to establish lot sizes to be used in defining a statistically satisfactory sampling method for the frequency of mechanical testing requirements of the specifications under the jurisdiction of Committee B-7. It is also developing a standard method of rounding off mechanical properties test results for inclusion in specifications developed by Committee B-7.

Subcommittee VII on Codification of Light Metals and Alloys, Cast and Wrought (R. B. Smith, chairman) prepared a new Tentative Recommended Practice for Temper Designation of Light Metals and Alloys, Cast and Wrought (B 296 – 54 T) which was presented to the Society through the Administrative Committee on Standards, and recommends that Tentative Recommended Practice for Codification of Light Metals and Alloys, Cast and Wrought (B 275 – 53 T) be adopted as standard without revision.

Subcommittee VIII on Atmospheric Exposure Tests (L. H. Adam, chairman) has test specimens of 27 aluminum and 11 magnesium alloys installed at five Society atmospheric exposure test sites: on top of the Port of Authority Building, New York City, for industrial atmospheric conditions; at State College, Pa., for rural; at Kure Beach, N. C., for Atlantic Coast marine; at Point Reyes, Calif., for Pacific Coast marine; and at Freeport, Tex., for Gulf Coast marine atmospheric conditions. Some of the specimens have been exposed for over three years and others for only one year, those at the Point Reyes and Freeport sites being the last installed. A paper on "Atmospheric Exposure of Wrought Aluminum and Magnesium

Alloys" based on these specimens after 1-yr exposure is appended to this report.[6]

This report has been submitted to letter ballot of the committee, which consists of 87 voting members; $54\frac{1}{6}$ members returned their ballots, of whom $47\frac{1}{2}$ have voted affirmatively and 0 negatively.

Respectfully submitted on behalf of the committee,

I. V. WILLIAMS,
Chairman.

R. B. SMITH,
Secretary.

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[6] See p. 284.

EDITORIAL NOTE

Subsequent to the Annual Meeting, Committee B-7 presented to the Society through the Administrative Committee on Standards the following recommendations:

Revision of Tentative Specifications for:

Aluminum and Aluminum-Alloy Sheet and Plate for Pressure Vessel Applications (B 178 - 54 T),
Aluminum and Aluminum-Alloy Sheet and Plate (B 209 - 54 T),
Aluminum-Alloy Drawn Seamless Tubes (B 210 - 54 T),
Aluminum and Aluminum-Alloy Bars, Rods, and Wire (B 211 - 54 T),
Aluminum and Aluminum-Alloy Extruded Bars, Rods, and Shapes (B 221 - 54 T),
Aluminum-Alloy Drawn Seamless Tubes for Condensers and Heat Exchangers (B 234 - 54 T),
Aluminum-Alloy Extruded Tubes (B 238 - 54 T),
Aluminum-Alloy Pipe (B 241 - 54 T),
Aluminum-Alloy Die Forgings (B 247 - 54 T),
Aluminum and Aluminum-Alloy Bars, Rods, and Shapes for Pressure Vessel Applications (B 273 - 54 T), and
Aluminum and Aluminum-Alloy Pipe and Tube for Pressure Vessel Applications (B 274 - 54 T).

These recommendations were accepted by the Standards Committee on October 17, 1955, and the revised specifications appear in the 1955 Book of ASTM Standards, Part 2, and in the January, 1956, Compilation of ASTM Standards on Light Metals and Alloys.

APPENDIX I

RECOMMENDATIONS AFFECTING STANDARDS FOR LIGHT METALS AND ALLOYS, CAST AND WROUGHT

In this Appendix are given the recommendations affecting certain standards covering light metals and alloys which are referred to earlier in this report. The standards appear in their present form in the 1952 Book of ASTM Standards, Part 2, the 1953 Supplement to Book of ASTM Standards, Part 2, or the 1954 Supplement to Book of ASTM Standards, Part 2.

REVISIONS OF TENTATIVES

The committee recommends that the following nine tentative specifications be revised as indicated below and continued as tentative:

Tentative Specifications for Aluminum-Base Alloy Sand Castings (B 26 – 54 T):[1]

Table I.—Revise to read as shown in the accompanying Table A. Footnotes *e* and *f* and Notes 1 to 3 remain unchanged.

New Section—Add a new Section 2 titled "Basis of Purchase" and renumber all succeeding sections. The new Section 2 shall read:

> 2. Orders for castings under this specification shall include the following information:
> (*1*) Quantity of each casting,
> (*2*) Alloy (Section 4, Table I),
> (*3*) Condition (Section 7, Table II),
> (*4*) Whether or not yield strength tests are required for alloys ZC81A, ZG32A, ZG42A, ZG61A, and ZG61B (Section 7, (*a*)),
> (*5*) Whether or not castings and/or test bars may be artificially aged for alloys ZC81A, ZG32A, ZG42A, and ZG61A (Section 7, (*b*)),
> (*6*) Place of inspection (Section 13, (*a*)), and
> (*7*) Whether general requirements shall be checked visually or by observational standards where such standards are established (Section 13, (*b*)).

Tentative Specifications for Magnesium-Base Alloy Sand Castings (B 80 – 54 T):[1]

New Section.—Add a new Section 2 titled "Basis of Purchase" and renumber all succeeding sections. The new Section 2 shall read:

> 2. Orders for castings under these specifications shall include the following information:
> (*1*) Quantity of each casting,
> (*2*) Alloy (Section 5, Table I),
> (*3*) Condition (Section 8, Table II), and
> (*4*) Place of inspection (Section 13(*a*)).

Table II.—Change the tensile strength of EK30A-T6 and EZ33A-T5 from "18,000" to "20,000" psi and change the elongation of the same alloys from "1" to "2" per cent.

Explanatory Note 2.—Add the following sentence at the end of the first paragraph: "In case of dispute, the 'Offset Method' shall be used."

Tentative Specifications for Magnesium-Base Alloy Sheet (B 90 – 51 T):[2]

New Section.—Add a new Section 2 titled "Basis of Purchase" and renumber all succeeding sections. The new Section 2 shall read:

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[1] 1954 Supplement to Book of ASTM Standards, Part 2.

[2] 1952 Book of ASTM Standards, Part 2.

TABLE A.—CHEMICAL REQUIREMENTS.[3]

(Revision of Table I, B 26.)

Alloy[f]	Aluminum, per cent	Copper, per cent	Iron, per cent	Silicon, per cent	Manganese, per cent	Magnesium, per cent	Zinc, per cent	Chromium, per cent	Titanium, per cent	Nickel, per cent	Other Elements, per cent	
											Each	Total
C4A	remainder	4.0 to 5.0	1.0	1.5	0.35	0.03	0.35	...	0.25	...	0.05	0.15
CG100A	remainder	9.2 to 10.8	1.5	2.0	0.50	0.15 to 0.35	0.8	...	0.25	0.50	...	0.35
CN42A	remainder	3.5 to 4.5	1.0	0.7	0.35	1.2 to 1.8	0.35	0.25	0.25	1.7 to 2.3	0.05	0.15
CS43A	remainder	3.5 to 4.5	1.2	2.5 to 3.5	0.50	0.05	1.0	...	0.25	0.35	...	0.50
CS72A	remainder	6.0 to 8.0	1.4	1.0 to 4.0	0.6	0.10	2.5	...	0.25	0.35	...	0.50
G4A	remainder	0.15[a]	0.50[a]	0.35	0.35[a]	3.5 to 4.5	0.15	...	0.25	...	0.05	0.15
G10A	remainder	0.25	0.30	0.25	0.15	9.5 to 10.6	0.15	...	0.25	...	0.05	0.15
GS42A	remainder	0.35[c]	0.6[c]	1.4 to 2.2	0.8[c]	3.5 to 4.5	0.35	0.25	0.25	...	0.05	...
S5A	remainder	0.15	0.8	4.5 to 6.0	0.35	0.05	0.35	...	0.25	...	0.05	...
S5B	remainder	0.6[b]	0.8	4.5 to 6.0	0.50	0.05	0.50	0.25	0.25	...	...	0.35
SC51A	remainder	1.0 to 1.5	0.8[d]	4.5 to 5.5	0.50[d]	0.40 to 0.6	0.35	0.25	0.25	...	0.05	0.15
SC64B	remainder	3.3 to 4.3	1.0	5.5 to 7.0	0.50	0.10	1.0	...	0.25	0.35	...	0.50
SC64C	remainder	3.0 to 4.5	1.2	5.5 to 7.0	0.8	0.50	1.0	...	0.25	0.50	...	0.50
SC82A	remainder	1.0 to 2.0	1.0	7.0 to 8.6	0.20 to 0.6	0.20 to 0.6	1.5	0.35	0.35	0.25	...	0.50
SG70A	remainder	0.25	0.6	6.5 to 7.5	0.35	0.20 to 0.40	0.35	...	0.25	...	0.05	0.15
ZC81A	remainder	0.40 to 1.0	1.0	0.35	0.6	0.20 to 0.50	7.0 to 8.0	0.35	0.25	0.15	0.15	0.25
ZG32A	remainder	0.20	0.8	0.20	0.40 to 0.6	1.4 to 1.8	2.7 to 3.3	0.20 to 0.40	0.25	...	0.05	...
ZG42A	remainder	0.20	0.8	0.20	0.40 to 0.6	1.8 to 2.4	4.0 to 4.5	0.20 to 0.40	0.25	...	0.05	...
ZG61A	remainder	0.30	1.0	0.25	0.30	0.50 to 0.65	5.2 to 6.0	0.40 to 0.6	0.10 to 0.25	...	0.05	0.25
ZG61B	remainder	0.35 to 0.65	0.50	0.15	0.05	0.6 to 0.8	6.0 to 7.0	...	0.25	...	0.05	0.15

[a] For cooking utensils copper 0.30 per cent, max, manganese 0 6 per cent, max, and iron 0.6 per cent, max, are permitted.

[b] For cooking utensils copper may be specified by the purchaser at 0.30 per cent, max.

[c] If copper + iron exceeds 0.50 per cent, a manganese content of at least 0.35 per cent is desirable.

[d] If the iron content exceeds 0.45 per cent, it is desirable to have the manganese present in an amount equal to one-half the iron.

2. Orders for sheet under these specifications shall include the following information:

(*1*) Quantity in pieces or pounds,
(*2*) Alloy (Section 4, Table I),
(*3*) Condition (Section 7, Table II),
(*4*) Thickness, width, and length, and
(*5*) Place of inspection (Section 14(*a*)).

Explanatory Note 2.—Add the following sentence at the end of the first paragraph: "In case of dispute, the 'Offset Method' shall be used."

Tentative Specifications for Magnesium-Base Alloy Forgings (B 91 – 54 T):[1]

New Section.—Add a new Section 2 titled "Basis of Purchase" and renumber all succeeding sections. The new Section 2 shall read:

2. Orders for forgings under these specifications shall include the following information:

(*1*) Quantity of each forging,
(*2*) Alloy (Section 4, Table I),
(*3*) Condition (Section 7, Table II), and
(*4*) Place of inspection (Section 12(*a*)).

Explanatory Note 3.—Add the following sentence at the end of the first paragraph: "In case of dispute, the 'Offset Method' shall be used."

Tentative Specifications for Magnesium-Base Alloys in Ingot Form for Sand Castings, Die Castings, and Permanent Mold Castings (B 93 – 52 T):[2]

New Section.—Add a new Section 2 titled "Basis of Purchase" and renumber all succeeding sections. The new Section 2 shall read:

2. Orders for ingots under these specifications shall include the following information:

(*1*) Quantity in pieces or pounds, and
(*2*) Alloy (Section 4, Table I).

Tentative Specifications for Magnesium-Base Alloy Bars, Rods, and Shapes (B 107 – 53 T):[3]

New Section.—Add a new Section 2 titled "Basis of Purchase" and renumber all succeeding sections. The new Section 2 shall read:

2. Orders for bars, rods, and shapes under these specifications shall include the following information:

(*1*) Quantity in pieces or pounds,
(*2*) Alloy (Section 4, Table I),
(*3*) Temper (Section 7, Table II),
(*4*) Length and cross sectional dimensions or drawing, and
(*5*) Place of inspection (Section 14(*a*)).

TABLE B.—PERMISSIBLE DEVIATION FROM STRAIGHT.
(Revision of Table V, B 107.)

Circumscribing Circle Diameter[a] (Shapes); Specified Diameter (Rod); Specified Width or Depth, Whichever Greater (Bar); in.	Minimum Thickness, in.	Permissible Variation from Straight,[b] in.	
		In Each Foot of Length	In Total Length of Piece
1½ and over	...	0.0125	length, ft, × 0.0125
Under 1½	Over 0.094	0.0125	length, ft, × 0.0125
Under 1½	0.094 and under	0.050	length, ft, × 0.050

[a] Diameter of smallest circle that will completely enclose the shape.
[b] When weight of shape on flat surface minimizes deviation.

Table III.—Change Footnote *c* to read as follows:

Where the space is completely enclosed (hollow shapes) the permissible variation for the width is the value in column 4 for a dimension equal to the depth, and conversely, but in no case is the permissible variation less than at the corners (column 2). *Example:* The width tolerance of a hollow shape having 1 by 3 in. rectangular outside dimensions is ±0.020 in., and the depth tolerance is ±0.032 in. The permissible variation at the corners (column 2) is ±0.024 in. for the width, and ±0.012 in. for the depth.

Change Footnote *d* to read as follows:

Where the dimensions specified are outside and inside, rather than the wall thickness itself, allowable deviation is ±10 per cent of mean wall thickness, maximum ±0.060 in., minimum ±0.010 in. (Mean wall thickness is the average of two wall thickness measurements taken at opposite sides of the void.)

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[3] 1953 Supplement to Book of ASTM Standards, Part 2.

Reference a new Footnote *f* adjacent to Footnote *d* in heading of column 3 to read as follows:

> In the case of class 1 hollow shapes, the standard wall thickness tolerance for round extruded tube is applicable. (Class 1 hollow shapes are those having a single round void 1 in. or more in diameter and having their weight equally distributed on opposite sides of two or more equally spaced axes.)

Table IV.—Delete Table IV, and renumber succeeding tables.

Table V.—Renumber as Table IV and revise as shown in the accompanying Table B.

Explanatory Note 2.—Add the following sentence at the end of the first paragraph: "In case of dispute, the 'Offset Method' shall be used."

Table IX.—Renumber as Table VIII, and revise to read as shown in the accompanying Table C.

TABLE C.—UNIT DEFORMATION VALUES.
(Revision of Table IX, B 107.)

Alloy and Temper	Yield Strength (0.2 per cent offset), min, psi	Unit Deformation, in. per in. of gage length
AZ31B	20 000 16 000	0.0051 0.0045
AZ61A	20 000 24 000 16 000	0.0051 0.0057 0.0045
AZ80A-F	28 000	0.0063
AZ80A-T51	30 000 32 000	0.0066 0.0069
ZK60A-F	31 000 28 000	0.0068 0.0063
ZK60A-T5	36 000 38 000	0.0075 0.0078

Tentative Specifications for Aluminum-Base Alloy Permanent Mold Castings (B 108 - 54 T):[1]

Table I.—Revise to read as shown in the accompanying Table D. All other footnotes and notes remain unchanged.

New Section.—Add a new Section 2 titled "Basis of Purchase" and renumber all succeeding sections. The new Section 2 shall read:

> 2. Orders for castings under this specification shall include the following information:
> (*1*) Quantity of each casting,
> (*2*) Alloy (Section 4, Table I),
> (*3*) Condition (Section 7, Table II),
> (*4*) Whether or not yield strength tests are required for alloys ZC81B, ZG32A, and ZG42A (Section 7, (*a*)),
> (*5*) Whether or not castings and/or test bars may be artificially aged for alloys ZC81B, ZG32A, and ZG42A (Section 7, (*b*)),
> (*6*) Place of inspection (Section 13, (*a*)), and
> (*7*) Whether general requirements shall be checked visually or by observational standards where such standards are established (Section 13, (*b*)).

Tentative Specifications for Magnesium-Base Alloy Permanent Mold Castings (B 199 - 54 T):[1]

New Section.—Add a new Section 2 titled "Basis of Purchase" and renumber all succeeding sections. The new Section 2 shall read:

> 2. Orders for castings under these specifications shall include the following information:
> (*1*) Quantity of each casting,
> (*2*) Alloy (Section 5, Table I),
> (*3*) Condition (Section 8, Table II), and
> (*4*) Place of inspection (Section 13(*a*)).

Explanatory Note 2.—Add a third sentence after the present sentence ending "(ASTM Designation: E 8)" as follows: "In case of dispute, the 'Offset Method' shall be used."

Tentative Specifications for Magnesium-Base Alloy Extruded Round Tubes (B 217 - 53 T):[3]

Title.—Delete the word "Round" from the title.

New Section.—Add a new Section 2 titled "Basis of Purchase" and renumber all succeeding sections. The new Section 2 shall read:

> 2. Orders for tubes under these specifications shall include the following information:
> (*1*) Quantity in pieces or pounds,

TABLE D.—CHEMICAL REQUIREMENTS.
(Revision of Table I, B 108.)

Alloy[a]	Aluminum, per cent	Copper, per cent	Iron, per cent	Silicon, per cent	Manganese, per cent	Magnesium, per cent	Zinc, per cent	Chromium, per cent	Titanium, per cent	Nickel, per cent	Other Elements, per cent	
											Each	Total
CG100A	remainder	9.2 to 10.8	1.5	2.0	0.50	0.15 to 0.35	0.8	...	0.25	0.50	...	0.35
CN42A	remainder	3.5 to 4.5	1.0	0.7	0.35	1.2 to 1.8	0.35	0.25	0.25	1.7 to 2.3	0.05	0.15
CS42A	remainder	4.0 to 5.0	1.2	2.0 to 3.0	0.35	0.05	0.50	...	0.25	0.35	...	0.35
CS66A	remainder	5.5 to 7.5	1.5	5.0 to 6.0	0.8	0.20 to 0.6	0.8	...	0.25	...	...	0.8
CS72A	remainder	6.0 to 8.0	1.4	1.0 to 4.0	0.6	0.10	2.5	...	0.25	0.35	...	0.50
CS104A	remainder	9.0 to 11.0	1.5	3.5 to 4.5	0.6	0.15 to 0.35	1.5	...	0.25	1.0	...	0.50
GS42A	remainder	0.35[b]	0.6[b]	1.4 to 2.2	0.8[b]	3.5 to 4.5	0.35	0.25	0.25	...	0.05	...
GZ42A	remainder	0.35[b]	0.6[b]	0.35	0.8[b]	3.5 to 4.5	1.4 to 2.2	...	0.25	...	0.05	...
S5A	remainder	0.15	0.8	4.5 to 6.0	0.35	0.05	0.35	...	0.25	...	0.05	...
S5B	remainder	0.6[a]	0.8	4.5 to 6.0	0.50	0.05	0.50	0.25	0.25	...	...	0.35
SC51A	remainder	1.0 to 1.5	0.8[c]	4.5 to 5.5	0.50[c]	0.40 to 0.6	0.35	0.25	0.25	...	0.05	0.15
SC64A	remainder	4.0 to 5.0	1.0	5.0 to 6.0	0.50	0.10	1.0	...	0.25	...	...	0.50
SC64B	remainder	3.3 to 4.3	1.0	5.5 to 7.0	0.50	0.10	1.0	...	0.25	0.35	...	0.50
SC64C	remainder	3.0 to 4.5	1.2	5.5 to 7.0	0.8	0.50	1.0	...	0.25	0.50	...	0.50
SC122A	remainder	1.0 to 2.0	0.9	11.0 to 13.0	0.50 to 0.9	0.40 to 1.0	1.0	...	0.25	0.05	...	0.50
SG70A	remainder	0.25	0.6	6.5 to 7.5	0.35	0.20 to 0.40	0.35	...	0.25	...	0.05	0.15
SN122A	remainder	0.50 to 1.5	1.3	11.0 to 13.0	0.35	0.7 to 1.3	0.35	...	0.25	2.0 to 3.0	0.05	...
ZC60A	remainder	0.35 to 0.65	1.4	0.35	0.05	0.25 to 0.45	6.0 to 7.0	...	0.25	...	0.05	0.15
ZC81B	remainder	0.40 to 1.0	1.3	0.35	0.6	0.20 to 0.50	7.0 to 8.0	0.35	0.25	0.15	0.15	0.25
ZG32A	remainder	0.20	0.8	0.20	0.40 to 0.6	1.4 to 1.8	2.7 to 3.3	0.20 to 0.40	0.25	...	0.05	...
ZG42A	remainder	0.20	0.8	0.20	0.40 to 0.6	1.8 to 2.4	4.0 to 4.5	0.20 to 0.40	0.25	...	0.05	...

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[a] For cooking utensils copper may be specified by purchaser at 0.30 per cent, max.

[b] If the copper content plus the iron content exceeds 0.50 per cent, a manganese content of at least 0.35 per cent is desirable.

[c] If the iron content exceeds 0.45 per cent, it is desirable to have manganese present in an amount equal to one-half of the iron.

(*2*) Alloy (Section 4, Table I),
(*3*) Temper (Section 7, Table II),
(*4*) Length and cross-sectional dimensions or drawing, and
(*5*) Place of inspection (Section 14(*a*)).

Table II.—Change the minimum tensile strength of AZ31B from "34,000" to "32,000" psi.

Table III.—Revise to add two size groups as shown in the accompanying Table E.

TABLE E.—PERMISSIBLE VARIATIONS IN DIAMETER.

(Revisions in Table III, B 217.)

Specified Diameter, in.	Permissible Variation in Diameter, ±, in.	
	Deviation of Mean Diameter from Specified Diameter	Deviation of Diameter at Any Point from Specified Diameter
10.000 to 11.999	0.055	0.125
12.000 to 12.875	0.065	0.150

Section 11.—Renumber as Section 12 and revise to read as follows:

12. (*a*) Variations from the specified dimensions for the type of material ordered shall not exceed the amounts prescribed in Tables III, IV, V, and VI.

(*b*) *Straightness.*—Tubes larger than ⅜ in. in outside diameter shall not vary from straight by an amount greater than 1 part in 960 parts (0.0625 in. in 5 ft). Tubes ⅜ in. or less in outside diameter shall be reasonably straight and free from kinks and sharp bends.

Table V.—Renumber as Table VII.

Explanatory Note 2.—Add the following sentence at the end of the first paragraph: "In case of dispute, the 'Offset Method' shall be used."

ADOPTION OF TENTATIVES AS STANDARD

The committee recommends that the following 12 tentative specifications be revised as indicated below and adopted as standard:

TABLE F.—PERMISSIBLE VARIATIONS IN WIDTH OR DEPTH FOR SQUARE, RECTANGULAR, HEXAGONAL, AND OCTAGONAL TUBES.

(New Table IV, B 217.)

Specified Width or Depth, in.	Permissible Variations in Width or Depth, ±, in.		
	Width or Depth at Corners from Specified Width or Depth	Width or Depth not at Corners from Specified Width or Depth	
		Square, Hexagonal, and Octagonal	Rectangular
½ to ¾, excl	0.012	0.020	The permissible variation for the width is the value for square, hexagonal, and octagonal tubing for a dimension equal to the depth, and conversely, but in no case is the permissible variation less than at the corners.[a]
¾ to 1, excl	0.014	0.020	
1 to 2, excl	0.018	0.025	
2 to 4, excl	0.025	0.035	
4 to 5, excl	0.035	0.045	
5 to 6, excl	0.045	0.055	

[a] *Example:* The width permissible variation of 1 by 3 in. rectangular tubing is ±0.025 in. and the depth permissible variation is ±0.035 in.

New Table.—Add a new Table IV as shown in the accompanying Table F.

Table IV.—Renumber as Table V and revise as shown in the accompanying Table G.

New Table.—Add a new Table VI as shown in the accompanying Table H.

Tentative Specifications for Aluminum and Aluminum-Alloy Sheet and Plate for Pressure Vessel Applications (B 178 – 54 T):[1]

Title.—Change to read: "Aluminum-Alloy Sheet and Plate for Pressure Vessel Applications."

TABLE G.—PERMISSIBLE VARIATIONS IN WALL THICKNESS FOR ROUND TUBES.

(Revision of Table IV, B 217.)

Specified Wall Thickness, in.[a]	Permissible Variations in Wall Thickness, ±, in.[b]				
	Mean Wall Thickness[c] from Specified Wall Thickness				Wall Thickness at Any Point from Mean Wall Thickness (Eccentricity)
	Under 1¼	1¼ to 3, excl	3 to 5, excl	5 and over	
Under 0.047	0.006	...	...	...	±10 per cent of mean wall thickness, with a maximum of 0.060 and a minimum of 0.010
0.047 to 0.061	0.007	0.008	0.008	0.010	
0.062 to 0.077	0.008	0.008	0.009	0.012	
0.078 to 0.124	0.009	0.009	0.010	0.015	
0.125 to 0.249	0.009	0.009	0.013	0.020	
0.250 to 0.374	0.011	0.011	0.016	0.025	
0.375 to 0.499	...	0.015	0.021	0.035	
0.500 to 0.749	...	0.020	0.028	0.045	
0.750 to 0.999	...	...	0.035	0.055	
1.000 to 1.499	...	...	0.045	0.065	
1.500 to 2.000	...	...	...	0.075	

[a] When dimensions specified are outside and inside rather than wall thickness itself, allowable deviation at any point (eccentricity) is ±10 per cent of the mean wall thickness; maximum ±0.060 in., minimum ±0.010 in.

[b] When outside diameter, inside diameter, and wall thickness are all specified, standard tolerances are applicable to any two of these dimensions, but not to all three.

[c] The mean wall thickness is determined by the average of two measurements taken opposite each other.

TABLE H.—PERMISSIBLE VARIATIONS IN WALL THICKNESS FOR SQUARE, RECTANGULAR, HEXAGONAL, AND OCTAGONAL TUBES.

(New Table VI, B 217.)

Specified Wall Thickness,[a] in.	Permissible Variations in Wall Thickness, ±, in.[b]			
	Mean Wall Thickness[c] from Specified Wall Thickness		Wall Thickness at Any Point from Mean Wall Thickness	
	Circumscribing Circle Diameter,[d] in.		Circumscribing Circle Diameter,[d] in.	
	Under 5	5 and Over	Under 5	5 and Over
Under 0.047	0.005	0.008	0.005	±10 per cent of mean wall thickness; maximum of 0.060, minimum of 0.010
0.047 to 0.061	0.006	0.009	0.007	
0.062 to 0.124	0.007	0.010	0.010	
0.125 to 0.249	0.008	0.015	0.015	
0.250 to 0.374	0.011	0.020	0.025	
0.375 to 0.499	0.014	0.030	0.030	
0.500 to 0.749	0.025	0.040	0.040	
0.750 to 0.999	0.035	0.050	0.050	
1.000 to 1.499	0.045	0.060	0.060	
1.500 to 2.000	...	0.070	...	

[a] When dimensions specified are outside and inside, rather than wall thickness itself, allowable deviation at any point (eccentricity) is ±10 per cent of the mean wall thickness; maximum ±0.060 in., minimum ±0.010 in.

[b] When outside diameter, inside diameter, and wall thickness are all specified, standard tolerances are applicable to any two of these dimensions, but not to all three.

[c] The "mean wall thickness" is determined by the average of two measurements taken opposite each other.

[d] The circumscribing circle diameter is the diameter of the smallest circle that will completely enclose the shape.

New Section.—Add a new Section 2 titled "Basis of Purchase" and renumber all succeeding sections. The new Section 2 shall read:

> 2. Orders for material under these specifications shall include the following information:
> (*1*) Quantity in pieces or pounds,
> (*2*) Alloy (Section 4),
> (*3*) Temper (Section 7),
> (*4*) Size (thickness, width, and length; or width and coil size if applicable), and
> (*5*) Place of inspection (Section 15).

Section 5.—Renumber as Section 6 and change the word "spectrographically" to read "spectrochemically."

Section 11.—Renumber as Section 12 and change title to read: "Permissible Variations in Dimensions."

Table I.—Add magnesium in the amount of 0.10 per cent max to cladding composition for alloys clad GS11A, clad M1A, and clad MG11A; revise left hand column under heading "Alloy [ag]" and add new column for AA alloy designations. First and second columns from left will then appear as follows:

Alloy		
ASTM[ag]		AA
990A		1100
996A		1160
G1A		5050
GM40A		5086
GR20A		5052
GR40A		5154
GS11A		6061
Clad GS11A	Core	6061
	Cladding	7072
M1A		3003
Clad M1A	Core	3003
	Cladding	7072
MG11A		3004
Clad MG11A	Core	3004
	Cladding	7072

Table II.—Change alloy headings to read as follows:

> ASTM Alloy 990A (AA Alloy 1100), ASTM Alloy 996A (AA Alloy 1160), ASTM Alloy G1A (AA Alloy 5050), ASTM Alloy GM40A (AA Alloy 5086), ASTM Alloy GR20A (AA Alloy 5052), ASTM Alloy GR40A (AA Alloy 5154), ASTM Alloy GS11A (AA Alloy 6061), ASTM Alloy Clad GS11A (AA Alloy Alclad 6061), ASTM Alloy M1A (AA Alloy 3003), ASTM Alloy Clad M1A (AA Alloy Alclad 3003), ASTM Alloy MG11A (AA Alloy 3004); ASTM Alloy Clad MG11A (AA Alloy Alclad 3004).

Revise values for alloy GR40A (AA alloy 5154) in all tempers as shown in the accompanying Table I_1.

TABLE I_1.—TENSILE REQUIREMENTS.
(Revisions in Table II, B 178.)

Temper	Thickness, in.	Tensile Strength, min, psi	Yield Strength, min, psi	Elongation in 2 in., min, per cent
O	0.051 to 0.113	30 000	11 000	16
	0.114 to 3.000	30 000	11 000	18
H32	0.051 to 0.249	36 000	26 000	8
	0.250 to 2.000	36 000	26 000	12
H34	0.051 to 0.161	39 000	29 000	6
	0.162 to 0.249	39 000	29 000	7
	0.250 to 1.000	39 000	29 000	10
H112	0.250 to 0.500	32 000	18 000	8
	0.501 to 2.000	30 000	11 000	11
	2.001 to 3.000	30 000	11 000	15

Revise values for Alloy GM40A for -O temper as shown in the accompanying Table I_2.

TABLE I_2.—TENSILE REQUIREMENTS.
(Revisions in Table II, B 178.)

O	less than 0.051	35 000[d]	14 000	15
	0.051 to 0.249	35 000[d]	14 000	18
	0.250 to 1.500	35 000[d]	14 000	14

Add Footnote *d* at bottom of table to read: "Alloy GM40A-0 has a maximum tensile strength requirement of 42,000 psi."

Table III.—Revise title to read: "Permissible Variations in Thickness of Alloys 996A (1160), 990A (1100), M1A (3003), Clad M1A (Alclad 3003), and G1A (5050) Flat Sheet, Coiled Sheet, and Plate, Plus or Minus, in." For thickness increment "2.251 to 2.750" and for width "over 102 to 132" add tolerance value of "0.125."

Table IV.—Revise title to read: "Permissible Variations in Thickness of Alloys GM40A (5086), GR20A (5052),

GR40A (5154), GS11A (6061), Clad GS11A (Alclad 6061), MG11A (3004), Clad MG11A (Alclad 3004) Flat Sheet, Coiled Sheet and Plate, Plus or Minus, in." In column headed "Over 96 to 120" and for thicknesses "0.321 to 0.438" correct broken type to read "0.033."

Tentative Specifications for Aluminum and Aluminum-Alloy Sheet and Plate (B 209 – 54 T):[1]

Title.—Change to read: "Aluminum-Alloy Sheet and Plate."

New Section.—Add a new Section 2 titled "Basis of Purchase" and renumber all succeeding sections. The new Section 2 shall read:

2. Orders for material under these specifications shall include the following information:
(*1*) Quantity in pieces or pounds,
(*2*) Alloy (Section 4),
(*3*) Temper (Section 7),
(4) Dimensions (thickness, width, and length; or width and coil size if applicable),
(*5*) Whether bend tests are required (Section 8), and
(*6*) Place of inspection (Section 16).

Table I.—Revise the left-hand column under heading "Alloy [e,f]" and add a new column for AA alloy designations. First and second columns from left will then appear as follows:

Alloy		
ASTM[e,f]		AA
990A		1100
CG42A		2024
Clad CG42A	Core	2024
	Cladding[d]	1230
Clad CS41A	Core	2014
	Cladding[d]	6003
G1A		5050
GM40A		5086
GR20A		5052
GS11A		6061
M1A		3003
MG11A		3004
ZG62A		7075
Clad ZG62A	Core	7075
	Cladding[d]	7072

Add chemical requirements for alloy GR40A as shown in the accompanying Table J.

Section 5.—Renumber as Section 6 and change the word "spectrographically" to read "spectrochemically."

Table II.—For alloy clad CG42A, change gage increments for -O temper to read:

0.010 to 0.032
0.033 to 0.062
0.063 to 0.499
0.500 to 1.750

For alloy clad CG42A, change gage increments for -T3 temper to read:

0.010 to 0.020
0.021 to 0.062
0.063 to 0.128
0.129 to 0.249

For alloy MG11A for -H32 temper in thickness range of 0.250 to 2.000 add elongation value of 6 per cent. For -H34 temper in thickness range of 0.250 to 1.000 add elongation value of 5 per cent. For alloy ZG62A for -O temper, change thickness increments to read "0.015 to 0.500" and for -T6 temper, change thickness increments to read:

0.015 to 0.044
0.045 to 0.500
0.501 to 1.000
1.001 to 2.000
2.001 to 2.500
2.501 to 3.000

For alloy clad ZG42A for -O temper change thickness increments to read "0.015 to 0.500" and for -T6 temper change thickness increments to read:

0.015 to 0.044
0.045 to 0.499
0.500 to 1.000
1.001 to 2.000
2.001 to 2.500
2.501 to 3.000

Change alloy headings to read as follows:

ASTM Alloy 990A (AA Alloy 1100), ASTM Alloy CG42A (AA Alloy 2024), ASTM Alloy Clad CG42A (AA Alloy Alclad 2024), ASTM Alloy Clad CS41A (AA Alloy Alclad 2014), ASTM Alloy G1A (AA Alloy 5050), ASTM Alloy GM40A (AA Alloy 5086), ASTM Alloy GR20A (AA Alloy 5052), ASTM Alloy GS11A (AA Alloy 6061), ASTM Alloy M1A (AA Alloy 3003), ASTM Alloy MG11A (AA Alloy 3004), ASTM Alloy ZG62A (AA Alloy 7075), ASTM Alloy Clad ZG62A (AA Alloy Alclad 7075).

Add requirements for alloy GR40A as shown in the accompanying Table K.

For alloy GM40A for -O temper revise requirements to read as shown in the accompanying Table K.

TABLE J.—CHEMICAL REQUIREMENTS.
(Revision in Table I, B 209.)

Alloy		Aluminum, per cent	Copper, per cent	Iron, per cent	Silicon, per cent	Manganese, per cent	Magnesium, per cent	Zinc, per cent	Chromium, per cent	Titanium, per cent	Other Elements, per cent	
ASTM[e,f]	AA										Each	Total
GR40A.....	5154.....	remainder	0.10	[c]	[c]	0.10	3.1 to 3.9	0.20	0.15 to 0.35	0.20	0.05	0.15

TABLE K.—PHYSICAL REQUIREMENTS.
(Revisions in Table II, B 209.)

Temper	Thickness, in.	Tensile Strength, psi	Yield Strength, min, psi[a]	Elongation in 2 in., min, per cent	Bend Diameter Factor N
		ALLOY GR40A (AA ALLOY 5154)			
O..........	0.020 to 0.031	41 000 max	11 000	12	...
	0.032 to 0.050	41 000 max	11 000	14	...
	0.051 to 0.113	41 000 max	11 000	16	...
	0.114 to 3.000	41 000 max	11 000	18	...
H32........	0.020 to 0.050	36 000 min	26 000	5	...
	0.051 to 0.249	36 000 min	26 000	8	...
	0.250 to 2.000	36 000 min	26 000	12	...
H34........	0.020 to 0.050	39 000 min	29 000	4	...
	0.051 to 0.161	39 000 min	29 000	6	...
	0.162 to 0.249	39 000 min	29 000	7	...
	0.250 to 1.000	39 000 min	29 000	10	...
H36........	0.020 to 0.050	42 000 min	32 000	3	...
	0.051 to 0.113	42 000 min	32 000	4	...
	0.114 to 0.161	42 000 min	32 000	5	...
H112.......	0.250 to 0.500	32 000 min	18 000	8	...
	0.501 to 2.000	30 000 min	11 000	11	...
	2.001 to 3.000	30 000 min	11 000	15	...
		ASTM ALLOY GM4OA (AA ALLOY 5086)			
O..........	less than 0.051	35 000 min[i]	14 000	15	...
	0.051 to 0.249	35 000 min[i]	14 000	18	...
	0.250 to 1.500	35 000 min[i]	14 000	14	...

Add Footnote *i* at bottom of table to read: "Alloy GM40A-0 has a maximum tensile requirement of 42,000 psi."

For alloy 990A and for temper -H16 revise present thickness range of "0.051 to 0.162" to read "0.051 to 0.161." For alloy 990A and for -H18 temper revise present thickness range of "0.051 to 0.128" to read "0.051 to 0.061." For alloy clad CS41A and for -T6 temper revise to read as shown in the accompanying Table L.

For alloy G1A and for -O temper revise present thickness range of "0.250 to 1.000" to read "0.250 to 3.000." For alloy G1A and for -H18 temper revise present thickness range of "0.051 to 0.113" to read "0.051 to 0.161." For alloy GM40A and for -H36 temper revise present thickness range of "0.051 to 0.125" to read "0.051 to 0.161."

TABLE L.—PHYSICAL REQUIREMENTS.
(Revisions in Table II, B 209.)

Temper	Thickness, in.	Tensile Strength, psi	Yield Strength, min, psi[a]	Elongation in 2 in., min, per cent	Bend Diameter Factor N
T6.........	0.020 to 0.039	63 000 min	55 000	7	...
	0.040 to 0.499	64 000 min	57 000	8	...
	0.500 to 1.000	67 000 min	59 000	6	...
	1.001 to 1.500	67 000 min	59 000	4	...
	1.501 to 2.000	65 000 min	59 000	3	...
	2.001 to 3.000	63 000 min	57 000	2	...

TABLE M.—PHYSICAL REQUIREMENTS.
(Revisions in Table II, B 209.)

Temper	Thickness, in.	Tensile Strength, psi	Yield Strength, min, psi[a]	Elongation in 2 in., min, per cent	Bend Diameter Factor N
H112.......	0.250 to 0.500	28 000 min	...	7	...
	0.501 to 2.000	25 000 min	...	12	...
	2.001 to 3.000	25 000 min	...	16	...

For alloy GR20A and for -H32 temper in thickness range "0.250 to 0.500" change elongation percentage from "9" to "11." For alloy GR20A and for -H36 temper change thickness range from "0.032 to 0.162" to read "0.032 to 0.161." For alloy GR20A and for -H38 temper change thickness range from "0.032 to 0.128" to read "0.032 to 0.161." For alloy GR20A delete all reference to "-F" temper and add "-H112" temper as shown in the accompanying Table M.

For alloy M1A and for -H16 temper change present thickness range of "0.051 to 0.162" to read "0.051 to 0.161." For alloy M1A and for -H18 temper change present thickness range from "0.051 to 0.128" to read "0.051 to 0.161." For alloy MG11A and for -H36 temper change present thickness range of "0.051 to 0.162" to read "0.051 to 0.161." For alloy MG11A and for -H38 temper change present thickness range of "0.051 to 0.128" to read "0.051 to 0.161."

In Footnote *e* change the value "0.063" in second line to read "0.062." Change the value "0.064" in third line to read "0.063."

Section 12(a).—Renumber as Section 13(*a*) and revise the cladding thickness table to appear as follows:

Alloy		Total Composite Thickness of Finished Sheet,[a] in.	Minimum Thickness of Cladding, in.
ASTM	AA		
Clad CG42A	Alclad 2024.........	0.062 and under..................	0.05 T[a]
		0.063 and over....................	0.025 T[a]
Clad CS41A	Alclad 2014.........	0.024 and under..................	0.10 T[a]
		0.025 to 0.039....................	0.075 T[a]
		0.040 to 0.101....................	0.05 T[a]
		0.102 and over....................	0.025 T[a]
Clad ZG62A	Alclad 7075.........	all..................................	0.04 T[a]

[a] "T" is the total composite thickness in inches.

Table III.—Revise title to read: "Permissible Variations in Thickness of Alloys 990A (AA Alloy 1100), G1A (AA Alloy 5050), and M1A (AA Alloy 3003) Flat Sheet, Coiled Sheet, and Plate, Plus or Minus, in."

Table IV.—Revise title to read: "Permissible Variations in Thickness of Alloys CG42A (AA Alloy 2024), Clad CG42A (AA Alloy Alclad 2024), GM40A (AA Alloy 5086), GR20A (AA Alloy 5052), GS11A (AA Alloy 6061), GR40A (AA Alloy 5154), Clad CS41A (AA Alloy Alclad 2014), MG11A (AA Alloy 3004), ZG62A (AA Alloy 7075), Clad ZG62A (AA Alloy Alclad 7075) Flat Sheet, Coiled Sheet, and Plate, Plus or Minus, in."

Section 13(b).—Renumber as Section 14(*b*), and revise to read:

> (*b*) *Length, Width, and Lateral Bow.*—Coiled sheet shall not vary in width or in lateral bow from that specified by more than the permissible variations prescribed in Tables V and VI, respectively. Flat sheet or plate shall not vary in width, length, or lateral bow from that specified by more than the permissible variations prescribed in Tables VII, VIII, and IX, respectively

New Tables.—Add Tables V, VI, VII, VIII, and IX as shown in the accompanying Tables N, O, P, Q, and R, respectively.

Tentative Specifications for Aluminum-Alloy Drawn Seamless Tubes (B 210 – 54 T):[1]

New Section.—Add a new Section 2 titled "Basis of Purchase" and renumber all succeeding sections. The new Section 2 shall read:

> 2. Orders for material under these specifications shall include the following information:
>
> (*1*) Quantity in pieces or pounds,
> (*2*) Alloy (Section 4),
> (*3*) Temper (Section 7),
> (*4*) Cross-sectional dimensions and length (for tube other than round, square, rectangular, hexagonal or octagonal with sharp corners, a drawing is required), and
> (*5*) Place of inspection (Section 14).

Table I.—Revise the left-hand column under heading "Alloy [bc]" and add a new column for AA alloy designations. First

TABLE N.—PERMISSIBLE VARIATIONS IN WIDTH OF COILED SHEET.

(New Table V, B 209.)

Thickness, in.	Permissible Variation in Widths, ±, in., for Widths Given in Inches			
	6 and under	Over 6 to 12	Over 12 to 24	Over 24 to 48
0.006 to 0.102........	0.010	0.016	1/32	3/64

TABLE O.—LATERAL BOW. PERMISSIBLE VARIATION OF A SIDE EDGE OF COILED SHEET FROM A STRAIGHT LINE.

(New Table VI, B 209.)

Thickness, in.	Permissible Bow, in., for Lengths Given in Inches			
	30 and under	Over 30 to 60	Over 60 to 90	Over 90 to 120
0.006 to 0.125........	1/16	1/4	1/2	1

TABLE P.—PERMISSIBLE VARIATION IN WIDTH OF FLAT SHEET AND PLATE.

(New Table VII, B 209.)

Thickness, in.	Permissible Variation in Width, in., for Widths Given in Inches					
	4 and under	Over 4 to 18	Over 18 to 36	Over 36 to 54	Over 54 to 72	Over 72 to 132
0.006 to 0.102..................	±1/32	±1/16	±3/32	±1/8	±5/32	±3/16
0.103 to 0.249..................	±1/8	±3/32	±1/8	±3/16	±3/16	±1/4
0.250 to 0.500..................	...	+3/8	+3/8	+3/8	+3/8	+3/8
0.501 to 1.000..................	...	+1/2	+1/2	+1/2	+1/2	+1/2
1.001 to 1.250..................	...	+5/8	+5/8	+5/8	+5/8	+5/8

TABLE Q.—PERMISSIBLE VARIATION IN LENGTH OF FLAT SHEET AND PLATE.
(New Table VIII, B 209.)

Thickness, in.	Permissible Variation in Length, in., for Lengths Given in Inches						
	18 and Under	Over 18 to 48	Over 48 to 120	Over 120 to 144	Over 144 to 180	Over 180 to 240	Over 240 to 540
0.006 to 0.249	±1/16	±3/32	±1/8	±5/32	±5/32	±1/4	±1/4
0.250 to 0.500	+3/8	+3/8	+3/8	+3/8	+7/16	+7/16	+1/2
0.501 to 1.000	+1/2	+1/2	+1/2	+1/2	+9/16	+9/16	+5/8
1.001 to 1.500	+5/8	+5/8	+5/8	+5/8	+3/4	+3/4	+1

and second columns from left will then appear as follows:

Alloy	
ASTM[bc]	AA
CG42A	2024
G1A	5050
GR20A	5052
GS11A	6061
GS11C	6062
M1A	3003
MG11A	3004

Section 5.—Renumber as Section 6 and change the word "spectrographically" to read "spectrochemically."

Table II.—Revise the left-hand column under the heading "Alloy" and add a new column to include AA alloy designations. First three columns from left of this table will then appear as shown below:

Alloy		Temper
ASTM	AA	
CG42A	2024	0 T3
G1A	5050	0 H34 H38
GR20A	5052	0 H34 H38
GS11A	6061	0 T4 T6
GS11C	6062	0 T4 T6
M1A	3003	0 H14 H18
MG11A	3004	0

Table IV.—Revise to appear as shown in the accompanying Table S.

Section 11(b).—Renumber as Section 12(*b*) and add the following before the last sentence: "For all sizes of other than round tube, straightness tolerance is applicable when weight of tube on flat surface minimizes deviation."

Tentative Specifications for Aluminum and Aluminum-Alloy Bars, Rods and Wire (B 211 - 54 T):[1]

Title.—Change to read: "Aluminum-Alloy Bars, Rods, and Wire."

Section 1.—Revise to read: "These specifications cover rolled or cold finished aluminum-alloy bars, rods and wire, and the aluminum alloys designated in Table I."

New Section.—Add a new Section 2 titled "Basis of Purchase" and renumber all succeeding sections. The new Section 2 shall read:

> 2. Orders for material under these specifications shall include the following information:
> (*1*) Quantity in pieces or pounds,
> (*2*) Alloy (Section 4),
> (*3*) Temper (Section 7),
> (*4*) Diameter for rounds, distance across flats for square-cornered squares, hexagons, or octagons, width and depth for square-cornered rectangles (orders for squares, hexagons, octagons, or rectangles with rounded corners usually require a drawing),
> (*5*) Length, and
> (*6*) Place of inspection (Section 14).

Table I.—Revise left hand column under the heading "Alloy [c]" and add new column for AA alloy designation. First

TABLE R.—LATERAL BOW. PERMISSIBLE VARIATION OF A SIDE EDGE OF FLAT SHEET FROM A STRAIGHT LINE.

(New Table IX, B 209.)

Width, in.	Thickness, in.	Permissible Bow, in., for Lengths Given in Inches								
		30 and under	Over 30 to 60	Over 60 to 90	Over 90 to 120	Over 120 to 144	Over 144 to 150	Over 150 to 180	Over 180 to 210	Over 210 to 240
Under 4	0.006 to 0.125	1/16	1/4	1/2	1	1 1/2	1 1/2	2	3	4
4 to 72	0.006 to 0.249	1/32	1/16	3/32	1/8	3/16	1 1/2	2	3	4

TABLE S.—PERMISSIBLE VARIATIONS IN WALL THICKNESS.

(Revision of Table IV, B 210.)

Nominal Wall Thickness, in.[a]	Permissible Variations in Wall Thickness, ±, in.			
	Mean[b]	Permissible Variation in Individual Measurement from Mean Wall Thickness		
	Alloys CG42A (2024), G1A (5050), GR20A (5052), GS11A (6061), GS11C (6062), M1A (3003), MG11A(3004)	Alloys G1A (5050), GR20A (5052), M1A (3003), Round Tube Only	Alloys CG42A (2024), GS11A (6061), GS11C (6062), Round Tube Only	All Alloys Other than Round Tube
0.010 to 0.035	0.002	0.002	10 per cent of nominal wall thickness, but not less than ±0.003 in.	
0.036 to 0.049	0.003	0.003		
0.050 to 0.083	0.004	0.004		
0.084 to 0.120	0.005	0.006		
0.121 to 0.203	0.006	0.008		
0.204 to 0.300	0.008	0.012		
0.301 to 0.375	0.015	0.020		
0.376 to 0.500	0.020	0.030		

[a] Intermediate wall thicknesses shall be rounded off to the third decimal place in accordance with Recommended Practice for Designating Significant Places in Specified Limiting Values (ASTM Designation: E 29).

[b] Mean wall thickness of round tube is the average of the two measurements of wall thickness taken at opposite sides of any diameter. The mean wall thickness of other-than-round tube is the average of two measurements taken opposite each other at approximate center line of the tube and perpendicular to the longitudinal axis of the cross section.

two columns from left of this table will then appear as follows:

Alloy	
ASTM[c]	AA
990A	1100
CG42A	2024
CM41A	2017
CB60A	2011
CS41A	2014
GR20A	5052
GS11A	6061
ZG62A	7075

Section 5.—Renumber as Section 6 and change the word "spectrographically" to read "spectrochemically."

Table II.—Revise the left-hand column under heading "Alloy" and add a new column to include AA alloy designations. First three columns from left will then appear as follows:

Alloy		Temper
ASTM	AA	
990A	1100	0
		H14
		H18
		F
CG42A	2024	0
		T4
CM41A	2017	0
		T4
CB60A	2011	T3
		T8
CS41A	2014	T4
		T6
GR20A	5052	H34
		H38
GS11A	6061	T4
		T6
ZG62A	7075	0
		T6

Tentative Specifications for Aluminum and Aluminum-Alloy Extruded Bars, Rods, and Shapes (B 221 – 54 T):[1]

Title.—Change to read: "Aluminum-Alloy Extruded Bars, Rods, and Shapes."

New Section.—Add a new Section 2 titled "Basis of Purchase" and renumber all succeeding sections. The new Section 2 shall read:

> 2. Orders for material under these specifications shall include the following information:
> (*1*) Quantity in pieces or pounds,
> (*2*) Alloy (Section 4),
> (*3*) Temper (Section 7),
> (*4*) Diameter (for rods), depth and width (for square cornered bars), distance across flats (for sharp cornered hexagonal or octagonal bars) (round cornered bars and shapes other than bar or rod require a drawing),
> (*5*) Length, and
> (*6*) Place of inspection (Section 14).

Table I.—Revise the left-hand column under heading "Alloy [cd]" and add a new column to include AA alloy designations. First two columns from left will then appear as follows:

Alloy	
ASTM[cd]	AA
990A	1100
CG42A	2024
CS41A	2014
GS10A	6063
GS11A	6061
GS11B	6053
GS11C	6062
M1A	3003
ZG62A	7075

Section 5.—Renumber as Section 6 and change the word "spectrographically" to read "spectrochemically."

Table II.—Revise the left-hand column under heading "Alloy" and add columns for AA alloy designations and area. Revised table will appear as shown in the accompanying Table T.

Table III.—Change footnotes as follows:

Revise Footnote *c* to read:

> Where the space is completely enclosed (hollow shapes) the tolerance for the width is the value in column 4 for a dimension equal to the depth, and conversely, but in no case is the tolerance less than at the corners (Column 2). *Example*: The width tolerance of a hollow shape having 1 in. by 3 in. rectangular outside dimensions is ±0.024 in. and the depth tolerance is ±0.032 in. Tolerance at the corners (Column 2) is ±0.024 in. for the width and ±0.012 in. for the depth.

Add the following sentence to Footnote *d*:

> (Mean wall thickness is the average of two wall thickness measurements taken at opposite sides of the void.)

Add a reference to new Footnote *f* adjacent to the present reference to Footnote *d*, the new footnote to read as follows:

TABLE T.—TENSILE REQUIREMENTS.

(Revision of Table II, B 221.)

Alloy		Temper	Thickness,[a] in.	Area, sq in.	Tensile Strength, min, psi	Yield Strength,[b] min, psi	Elongation[c] in 2 in. or 4D,[d], min, per cent
ASTM	AA						
990A	1100	0	all sizes	...	15 500[h]	...	25
		F	all sizes	...	...[i]	...[i]	...
CG42A	2024	0	all sizes	all sizes	35 000[h]	19 000[h]	12
		T4[e]	0.050 to 0.249	all sizes	57 000	42 000	12
			0.250 to 0.749	all sizes	60 000	44 000	12
			0.750 to 1.499	all sizes	65 000	46 000	10
			1.500 and over	25 and under	70 000	52 000	10
			1.500 and over	over 25 to 32	68 000	48 000	8
CS41A	2014	0	all sizes	all sizes	30 000[h]	18 000[h]	12
		T4[f]	all sizes	all sizes	50 000	35 000	12
		T6[g]	0.125 to 0.499	all sizes	60 000	53 000	7
			0.500 to 0.749	all sizes	64 000	58 000	7
			0.750 and over	25 and under	68 000	60 000	7
			0.750 and over	over 25 to 32	68 000	58 000	6
GS10A	6063	T4	0.500 and under	all sizes	22 000	10 000	14
		T42	0.500 and under	all sizes	17 000	10 000	12
		T5	0.500 and under	all sizes	22 000	16 000	8
		T6	0.124 and under	all sizes	30 000	25 000	8
			0.125 to 0.500	all sizes	30 000	25 000	10
GS11A	6061	0	all sizes	all sizes	22 000[h]	16 000[h]	16
		T4	all sizes	all sizes	26 000	16 000	16
		T6	all sizes	all sizes	38 000	35 000	10
		T62	all sizes	all sizes	35 000	26 000	10
GS11B	6053	0	all sizes	all sizes	19 000[h]	...	18
		T4	all sizes	all sizes	25 000	14 000	16
		T6	all sizes	all sizes	32 000	25 000[j]	10
GS11C	6062	0	all sizes	all sizes	22 000[h]	16 000[h]	16
		T4	all sizes	all sizes	26 000	16 000	16
		T6	all sizes	all sizes	38 000	35 000	10
M1A	3003	0	all sizes	all sizes	19 000[h]	...	25
		F	all sizes	all sizes	...[i]	...[i]	...
ZG62A	7075	0	all sizes	all sizes	40 000[h]	24 000[h]	10
		T6	0.249 and under	all sizes	78 000	70 000	7
			0.250 to 2.999	all sizes	80 000	72 000	7
			3.000 to 4.499	20 and under	80 000	70 000	7
			3.000 to 4.499	over 20 to 32	78 000	70 000	6
			4.500 to 5.000	32 and under	78 000	68 000	6

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[a] Specimens tested parallel to direction of extrusion.

[b] Yield strength is defined as the stress which produces a permanent set of 0.2 per cent of the initial gage length.

[c] For material for which a standard test specimen cannot be taken, or for material thinner than 0.062 in., the test for elongation is not required.

[d] *D* represents specimen diameter.

[e] CG42A material heat treated by the purchaser regardless of thickness shall develop a minimum

In the case of class 1 hollow shapes, the standard wall thickness tolerance for round extruded tube is applicable. (Class 1 hollow shapes are those having a single round void one inch or more in diameter and having their weight equally distributed on opposite sides of two or more equally spaced axes.)

Table IV.—Revise to read as shown in the accompanying Table U.

TABLE U.—PERMISSIBLE DEVIATION FROM STRAIGHT.

(Revision of Table IV, B 221.)

Circumscribing Circle Diameter[a] (Shapes); Specified Diameter (Rod); Specified Width or Depth, Whichever Greater (Bar), in.	Minimum Thickness, in.	Permissible Variation from Straight,[b,c] in.	
		In Each Foot of Length	In Total Length of Piece
1½ and over..............	...	0.0125	length, ft, × 0.0125
Under 1½................	Over 0.094	0.0125	length, ft, × 0.0125
Under 1½................	0.094 and under	0.050	length, ft, × 0.050

[a] Diameter of smallest circle that will completely enclose the shape.

[b] Not applicable to material in the annealed temper.

[c] When weight of shape on flat surface minimizes deviation.

Table V.—Revise the heading of the left-hand column from "Circumscribed Circle Diameter, in.[a]," to "Circumscribing Circle Diameter (Shapes);[a] Specified Width or Depth, Whichever Greater (**Bar**), in."

Tentative Specifications for Aluminum-Alloy Drawn Seamless Tubes for Condensers and Heat Exchangers (B 234 - 54 T):[1]

Scope.—Revise Section 1 to read: "These specifications cover drawn seamless tube in four types . . . ."

New Section.—Add a new Section 2 titled "Basis of Purchase" and renumber all succeeding sections. The new Section 2 shall read:

2. Orders for material under these specifications shall include the following information:

(*1*) Quantity in pieces or pounds,
(*2*) Alloy (Section 4),
(*3*) Temper (Section 7),
(*4*) Outside diameter and wall thickness or inside diameter and wall thickness,
(*5*) Length, and
(*6*) Place of inspection (Section 17).

Table I.—Revise the left-hand column under heading "Alloy" and add a new column to show AA alloy designations. First and second columns from left will then appear as follows:

Alloy	
ASTM[b]	AA
GS11A..............	6061.........
GS11C..............	6062.........
M1A................	3003.........
M1A Clad...........	Alclad 3003.........
Core...............	3003.........
Coating............	7072.........

Section 5.—Renumber as Section 6 and change the word "spectrographically" to read "spectrochemically."

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tensile strength of 57,000 psi, a minimum yield strength of 38,000 psi, and an elongation of 12 per cent minimum. The temper of such material is T42.

[f] CS41A material heat treated by the purchaser shall develop a minimum yield strength of 29,000 psi and is properly designated as T42 temper.

[g] CS41A material heat treated and aged by the purchaser regardless of thickness shall develop a minimum tensile strength of 60,000 psi and a minimum yield strength of 53,000 psi. The temper of such material is T62.

[h] Maximum.

[i] There are no tensile requirements for alloys 990A and M1A in the "F" temper but the tensile strength of alloy 990A in the "F" (as extruded) condition is about 13,000 to 17,000 psi and of alloy M1A about 16,000 to 21,000 psi, the lower values being associated with thick or bulky sections.

[j] Yield strength not to exceed 80 per cent of the tensile strength.

Table II.—Add values for alloys GS11A and GS11C in the -T4 temper as shown in the accompanying Table V.

Section 14.—Renumber as Section 15 and revise to read as follows:

> Diameter and wall thickness tolerances for alloys GS11A and GS11C shall be the subject of negotiation between the manufacturer and purchaser. Length and straightness tolerances for alloys GS11A and GS11C shall be as specified in Section 15(*c*) and (*d*). Diameter, wall thickness, length, and straightness tolerances for alloys M1A and M1A clad shall be as specified in Sections 15(*a*), (*b*), (*c*), and (*d*), respectively.

TABLE V.—TENSILE REQUIREMENTS.
(Revisions in Table II, B 234)

Alloy		Temper	Wall Thickness, in.	Tensile Strength, min, psi	Yield Strength, min, psi	Elongation in 2 in. or 4 × Diameter, min, per cent	
ASTM	AA					Full-Section Specimens	Cut-Out Specimens
GS11A	6061	T4.........	0.025 to 0.049	30 000	16 000	16	14
			0.050 to 0.259	30 000	16 000	18	16
			0.260 to 0.500	30 000	16 000	20	18
GS11C	6062	T4.........	0.025 to 0.049	30 000	16 000	16	14
			0.050 to 0.259	30 000	16 000	18	16
			0.260 to 0.500	30 000	16 000	20	18

The balance of Section 15 is to remain unchanged.

Appendix.—Revise the second paragraph of the appendix to these specifications to read:

> Alloys M1A and M1A clad are supplied in a strain hardened temper to meet the specified tensile and yield strengths. Alloys GS11A and GS11C are supplied in the heat treated temper (-T4) and in the heat treated and aged temper (-T6). These alloys (GS11A and GS11C) are more workable in the -T4 temper, and after forming work is completed may be subsequently aged to the stronger -T6 temper. A typical aging treatment would be to hold the material at 350 F for 6 to 10 hr in a suitable furnace and allow to cool at room temperature.

Tentative Specifications for Aluminum-Alloy Extruded Tubes (B 235 - 54 T):[1]

New Section.—Add a new Section 2 titled "Basis of Purchase" and renumber all succeeding sections. The new Section 2 shall read:

> 2. Orders for material under these specifications shall include the following information:
> (*1*) Quantity in pieces or pounds,
> (*2*) Alloy (Section 4),
> (*3*) Temper (Section 7),
> (*4*) Diameter or distance across flats and wall thickness for round, square, hexagonal, or octagonal tube with square or sharp corners (for tube other than round, square, rectangular, hexagonal, or octagonal with sharp corners, a drawing is required),
> (*5*) Length, and
> (*6*) Place of inspection (Section 13).

Table I.—Revise the left-hand column under heading "Alloy[ab]" and add a new column to include AA alloy designations. First and second columns from left will then appear as follows:

Alloy	
ASTM[ab]	AA
CG42A...............	2024...............
CS41A...............	2014...............
GS10A...............	6063...............
GS11A...............	6061...............
GS11C...............	6062...............
M1A...............	3003...............
ZG62A...............	7075...............

Table II.—Revise the table to appear as shown in the accompanying Table W.

TABLE W.—TENSILE REQUIREMENTS.

(Revision of Table II, B 235.)

Alloy		Temper	Wall Thickness, in.	Tensile Strength, psi	Yield Strength,[a] psi	Elongation in 2 in. or 4 × Diameter, min, per cent
ASTM	AA					
CG42A	2024	O	all sizes	35 000 max	19 000 max	12
		F	all sizes	...[f]	...[f]	...[f]
		T4[b]	0.499 and under	60 000 min	40 000 min	10
			0.500 to 1.499	65 000 min	46 000 min	10
			1.500 and over[e]	70 000 min	48 000 min	10
CS41A	2014	O	all sizes	30 000 max	18 000 max	12
		F	all sizes	...[f]	...[f]	...[f]
		T4[c]	0.499 and under	50 000 min	30 000 min	12
			0.500 and over	55 000 min	35 000 min	12
		T6[d]	0.125 to 0.499	60 000 min	53 000 min	7
			0.500 to 0.749	64 000 min	58 000 min	7
			0.750 and over[e]	68 000 min	60 000 min	7
GS10A	6063	O	all sizes	19 000 max	...	18
		T42	0.500 and under	17 000 min	10 000 min	12
		T4	0.500 and under	22 000 min	10 000 min	14
		T5	0.500 and under	22 000 min	16 000 min	10
		T6	0.500 and under	30 000 min	25 000 min	8
GS11A	6061	O	all sizes	22 000 max	16 000 max	16
		F	all sizes	...[f]	...[f]	...[f]
		T4	all sizes	26 000 min	16 000 min	16
		T6	all sizes	38 000 min	35 000 min	10
		T62	all sizes	35 000 min	26 000 min[g]	10
GS11C	6062	O	all sizes	22 000 max	16 000 max	16
		F	all sizes	...[f]	...[f]	...[f]
		T4	all sizes	26 000 min	16 000 min	16
		T6	all sizes	38 000 min	35 000 min	10
		T62	all sizes	35 000 min	26 000 min[g]	10
M1A	3003	O	all sizes	19 000 max	...	25
		F	all sizes	...[f]	...[f]	...[f]
ZG62A	7075	O	all sizes	40 000 max	24 000 max	10
		F	all sizes	...[f]	...[f]	...[f]
		T6	0.249 and under	78 000 min	70 000 min	7
			0.250 to 2.999	80 000 min	72 000 min	7

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[a] Yield strength is defined as the stress which produces a permanent set of 0.2 per cent of the initial gage length.

[b] Tubes heat treated or reheat-treated by the purchaser, regardless of wall thickness, shall be designated T42 and shall develop a minimum tensile strength of 57,000 psi and minimum yield strength of 38,000 psi.

[c] Tubes heat treated or reheat-treated by the purchaser are designated T42 and shall develop a minimum yield strength of 29,000 psi.

[d] Tubes heat treated and aged or reheat-treated and aged by the purchaser, regardless of wall thickness, are designated T62 and shall develop a minimum tensile strength of 60,000 psi, and a minimum yield strength of 53,000 psi.

[e] Maximum cross-sectional area of wall, 25 sq in.; for larger cross-sectional areas, consult manufacturer

[f] Not required.

[g] Yield strength not to exceed 80 per cent of the tensile strength.

Section 5.—Renumber as Section 6 and change the word "spectrographically" to read "spectrochemically."

Table III.—Change the last line in the first column to read: "12 to 12⅞, incl."

Table IV.—Change the last line in the first column to read "4 to 5, excl," and add a new line to read "5 to 6, incl." Add values of "0.045" and "0.055" in second and third columns from left respectively.

Table V.—Revise to read as shown in the accompanying Table X.

Table VI.—Revise this table to appear as shown in the accompanying Table Y.

Tentative Specifications for Aluminum Bars for Electrical Purposes (B 236 – 52 T):[2]

These specifications have been extensively revised and are appended hereto.[4]

Tentative Specifications for Aluminum-Alloy Pipe (B 241 – 54 T):[1]

New Section.—Add a new Section 2 titled "Basis of Purchase" and renumber all succeeding sections. The new Section 2 shall read:

2. Orders for material under these specifications shall include the following information:

(*1*) Quantity in pieces or pounds,
(*2*) Alloy (Section 4),
(*3*) Temper (Section 7),
(*4*) Pipe size and schedule number,
(*5*) Length,
(*6*) Place of inspection (Section 14), and
(*7*) Plain or threaded ends (Section 13(*b*)).

Section 5.—Renumber as Section 6 and change the word "spectrographically" to read "spectrochemically."

Table I.—Revise the headings for second, third, fourth, and fifth columns from left to read as follows:

(Revision in Table I, B 241.)

ASTM Alloy GS10A (AA Alloy 6063)	ASTM Alloy GS11A (AA Alloy 6061)	ASTM Alloy GS11C (AA Alloy 6062)	ASTM Alloy M1A (AA Alloy 3003)

Table II.—Revise left hand column and add new column to show AA alloy designation. First three columns from left will then appear as follows:

Alloy		Temper
ASTM[b]	AA	
GS10A	6063	T5 T6
GS11A	6061	T6
GS11C	6062	T6
M1A	3003	H18 H112

For alloy GS10A and for -T6 temper under column headed "Tensile Strength, min, psi" revise the figure "32,000" to read "30,000."

Table III.—Revise the headings for fourth, fifth, seventh, and eighth columns from left to include AA alloy designations. Reading from left to right column headings will then appear as follows:

(Revision in Table III, B 241.)

Alloys GS10A (6063), GS11A (6061), and GS11C (6062)	Alloy M1A (3003)	Alloys GS10A (6063), GS11A (6061), and GS11C (6062)	Alloy M1A (3003)

Tentative Specifications for Aluminum-Alloy Die Forgings (B 247 – 54 T):[1]

New Section.—Add a new Section 2 titled "Basis of Purchase" and renumber all succeeding sections. The new Section 2 shall read:

2. Orders for material under these specifications shall include the following information:

(*1*) Quantity in pieces or pounds,
(*2*) Alloy (Section 4),
(*3*) Temper (Section 7),
(*4*) Dimensions (a drawing is required), and
(*5*) Place of inspection (Section 15).

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[4] The revised tentative appears in the 1955 Book of ASTM Standards, Part 2.

TABLE X.—PERMISSIBLE VARIATIONS IN WALL THICKNESS FOR ROUND TUBES.

(Revision of Table V, B 235.)

Specified Wall Thickness[a]	Permissible Variations in Wall Thickness, ±, in. [b]				
	Mean Wall Thickness[a] from Specified Wall Thickness				Wall Thickness at Any Point from Mean Wall Thickness (Eccentricity)
	Under 1¼	1¼ to 3, excl	3 to 5, excl	5 and over	
Under 0.047	0.006	...	...	...	
0.047 to 0.061	0.007	0.008	0.008	0.010	±10 per cent of mean wall thickness; maximum of 0.060 in., minimum of 0.010 in.
0.062 to 0.077	0.008	0.008	0.009	0.012	
0.078 to 0.124	0.009	0.009	0.010	0.015	
0.125 to 0.249	0.009	0.009	0.013	0.020	
0.250 to 0.374	0.011	0.011	0.016	0.025	
0.375 to 0.499	...	0.015	0.021	0.035	
0.500 to 0.749	...	0.020	0.028	0.045	
0.750 to 0.999	...	...	0.035	0.055	
1.000 to 1.499	...	...	0.045	0.065	
1.500 to 2.000	...	...	...	0.075	

[a] When dimensions specified are outside and inside rather than wall thickness itself, allowable deviation at any point (eccentricity) is ±10 per cent of the mean wall thickness; maximum ±0.060 in., minimum ±0.010 in.

[b] When outside diameter, inside diameter, and wall thickness are all specified, standard tolerances are applicable to any two of these dimensions, but not to all three.

[c] The "mean wall thickness" is determined by the average of two measurements taken opposite each other.

TABLE Y.—PERMISSIBLE VARIATIONS IN WALL THICKNESS FOR SQUARE, RECTANGULAR, HEXAGONAL, AND OCTAGONAL TUBES.

(Revision of Table VI, B 235.)

Specified Wall Thickness,[a] in.	Permissible Variations in Wall Thickness, ±, in.[b]			
	Mean Wall Thickness[c] from Specified Wall Thickness		Wall Thickness at Any Point from Mean Wall Thickness	
	Circumscribing Circle Diameter,[d] in.		Circumscribing Circle Diameter,[d] in.	
	Under 5	5 and over	Under 5	5 and over
Under 0.047	0.005	0.008	0.005	
0.047 to 0.061	0.006	0.009	0.007	±10 per cent of mean wall thickness; maximum of 0.060 in., minimum of 0.010 in.
0.062 to 0.124	0.007	0.010	0.010	
0.125 to 0.249	0.008	0.015	0.015	
0.250 to 0.374	0.011	0.020	0.025	
0.375 to 0.499	0.014	0.030	0.030	
0.500 to 0.749	0.025	0.040	0.040	
0.750 to 0.999	0.035	0.050	0.050	
1.000 to 1.499	0.045	0.060	0.060	
1.500 to 2.000	...	0.070	...	

[a] When dimensions specified are outside and inside, rather than wall thickness itself, allowable deviation at any point (eccentricity) is ±10 per cent of the mean wall thickness; maximum ±0.060 in., minimum ±0.010 in.

[b] When outside diameter, inside diameter, and wall thickness are all specified, standard tolerances are applicable to any two of these dimensions, but not to all three.

[c] The "mean wall thickness" is determined by the average of two measurements taken opposite each other.

[d] The circumscribing circle diameter is the diameter of the smallest circle that will completely enclose the shape.

Section 5.—Renumber as Section 6 and change the word “spectrographically” to read “spectrochemically.”

Table I.—Revise the left-hand column under heading “Alloy[d]” and add a new column to include AA alloy designations. First and second columns from left will then appear as follows:

Alloy	
ASTM[d]	AA
990A	1100
CN42C	2018
CN42D	2218
CS41A	2014
CS41C	2025
GS11A	6061
GS11B	6053
M1A	3003
SG11A	6151
SG121A	4032
ZG62A	7075

Table II.—Revise the left-hand column under the heading “Alloy” and add a new column to show AA alloy designations. First and second columns from left will then appear as follows:

Alloy	
ASTM	AA
990A	1100
CN42C	2018
CN42D	2218
CS41A	2014
CS41A	2014
CS41C	2025
GS11A	6061
GS11B	6053
M1A	3003
SG11A	6151
SG121A	4032
ZG62A	7075

Tentative Specifications for Aluminum and Aluminum-Alloy Bars, Rods, and Shapes for Pressure Vessel Applications (B 273 – 54 T):[1]

Title.—Change to read: “Aluminum-Alloy Bars, Rods, and Shapes for Pressure Vessel Applications.”

New Section.—Add a new Section 2 titled “Basis of Purchase” and renumber all succeeding sections. The new Section 2 shall read:

2. Orders for material under these specifications shall include the following information:

(*1*) Quantity in pieces or pounds,
(*2*) Alloy (Section 4),
(*3*) Temper (Section 7),
(*4*) Diameter (for rods), depth and width (for square cornered bars), distance across flats (for sharp cornered hexagonal or octagonal bars) (round cornered bars, and shapes other than bar or rod require a drawing),
(*5*) Length, and
(*6*) Place of inspection (Section 14).

Section 5.—Renumber as Section 6 and change the word “spectrographically” to read “spectrochemically.”

Table I.—Revise the left-and column under heading “Alloy[a]” and add a new column to show AA alloy designations. First and second columns from left will then appear as follows:

Alloy	
ASTM[a]	AA
990A	1100
CG42A	2024
CS41A	2014
GS11A	6061
GS11C	6062
M1A	3003
GR40A	5154

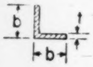
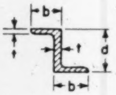
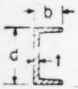
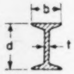
For alloy CS41A revise the figure under column headed “Chromium, per cent” from “0.25” to read “0.10.”

Table II.—Add a new column (second from left) to show AA alloy designations. First three columns from left will then appear as follows:

Alloy		Temper
ASTM	AA	
990A	1100	O H112
CG42A	2024	T4
CS41A	2014	T4 T6
GR40A	5154	O H112
GS11A	6061	T4 T6
GS11C	6062	T4 T6
M1A	3003	O H112

TABLE Z.—PERMISSIBLE VARIATIONS IN DIMENSIONS OF ROLLED OR EXTRUDED STRUCTURAL SHAPES.

(Revision of Table VII, B 273.)

Shape	Dimensions, in.		Permissible Variations in Dimensions, ±	
			per cent	in.
Angles up through 8 by 8 in.		*t* thickness	2½	0.010 min
		b flange width	2½	1/16 min
Zees up through 6 by 6 in.		*t* thickness	2½	0.010 min
		b flange width	2½	1/16 min
		d depth	2½	1/16 min
Channels up through 15 in.		*t* thickness	2½	0.010 min[a]
		b flange width	4	...
		d depth	...	+3/32, −1/16
I-Beams up through 15 in.		*t* thickness	2½	0.010 min[a]
		b flange width	4	...
		d depth	...	+3/32, −1/16

[a] For some sizes produced by extrusion, greater tolerances may be required.

TABLE AA.—PERMISSIBLE DEVIATION FROM STRAIGHT FOR EXTRUDED BARS, RODS, AND SHAPES.

(Revision of Table VIII, B 273.)

Circumscribing Circle Diameter (Shapes)[a]; Specified Diameter (Rod); Specified Width or Depth, Whichever Greater (Bar), in.	Minimum Thickness, in.	Allowable Deviation from Straight[b, c] in.	
		In Each Foot of Length	In Total Length of Piece
1½ and over	...	0.0125	length, ft, × 0.0125
Under 1½	over 0.094	0.0125	length, ft, × 0.0125
Under 1½	0.094 and under	0.050	length, ft, × 0.050

[a] Diameter of the smallest circle that will completely enclose the shape.

[b] Not applicable to material in the annealed temper.

[c] When weight of shape on flat surface minimizes deviation.

Table III.—Revise footnotes as follows:

Revise Footnote *c* to read:

Where the space is completely enclosed (hollow shapes) the tolerance for the width is the value in column 4 for a dimension equal to the depth, and conversely, but in no case is the tolerance less than at the corners (column 2). *Example:* The width tolerance of a hollow shape having 1 by 3-in. rectangular outside dimensions is ±0.024 in. and the depth tolerance is ±0.032 in. Tolerance at the corners (column 2) is ±0.024 in. for the width and ±0.012 in. for the depth.

Add the following sentence at the end of Footnote *d*: "(Mean wall thickness is the average of two wall thickness measurements taken at opposite sides of the void)".

Reference a new Footnote *f* adjacent to the present reference to Footnote *d*, the new footnote to read as follows: "In the case of class 1 hollow shapes, the standard wall thickness tolerance for round extruded tube is applicable. (Class 1 hollow shapes are those having a single round void 1 in. or more in diameter, and having their weight equally distributed on opposite sides of two or more equally spaced axis)."

Table VII.—Revise table to read as shown in the accompanying Table Z.

Table VIII.—Revise table to read as shown in the accompanying Table AA.

Table IX.—Revise the heading of the left-hand column to read as follows: "Circumscribing circle diameter (shapes)[a]; specified width or depth, whichever greater (bar), in."

Table X.—Revise this table to read as shown in the accompanying Table BB.

Tentative Specifications for Aluminum and Aluminum-Alloy Pipe and Tube for Pressure Vessel Applications (B 274 – 54 T):[1]

Title.—Change to read: "Aluminum-Alloy Pipe and Tube for Pressure Vessel Applications."

New Section.—Add a new Section 2 titled "Basis of Purchase" and renumber all succeeding sections. The new Section 2 shall read:

2. Orders for material under these specifications shall include the following information:

(*1*) Quantity in pieces or pounds,
(*2*) Alloy (Section 4),
(*3*) Temper (Section 7),
(*4*) Outside diameter and wall thickness, or inside diameter and wall thickness for tube; pipe size and schedule number for pipe,
(*5*) Length,
(*6*) Plain or threaded ends (Section 15(*b*)), and
(*7*) Place of inspection (Section 16).

TABLE BB.—PERMISSIBLE DEVIATION FROM STRAIGHT FOR ROLLED OR COLD-FINISHED BARS AND RODS.

(Revision of Table X, B 273.)

Tolerance, in.[a]	
Drawn or Cold Finished	Rolled
length, ft × 0.025 Minimum tolerance 0.125	length, ft × 0.050 Minimum tolerance 0.250

[a] Not applicable to material in the annealed ("O" temper) condition, or to coiled material.

Table I.—Revise the left-hand column under heading "Alloy[e]" and add a new column to show AA alloy designations. First two columns from left will then appear as follows:

Alloy	
ASTM[e]	AA
996A	1160
CG42A	2024
CS41A	2014
G1A	5050
GR20A	5052
GR40A	5154
GS10A	6063
GS11A	6061
GS11C	6062
M1A	3003
Clad M1A Core	3003
Clad M1A Coating	7072
MG11A	3004

For coating of Alloy Clad M1A in column headed "Magnesium, per cent" add the value "0.10."

Section 5.—Renumber as Section 6 and

change the word "spectrographically" to read "spectrochemically."

Table II.—Revise the left-hand column under heading "Alloy" and add a new column to show AA alloy designations. First three columns from left will then appear as shown in the accompanying Table CC.

TABLE CC.—TENSILE REQUIREMENTS.
(Revisions in Table II, B 274.)

Alloy		Temper
ASTM	AA	
996A	1160	O
		H112
		H14
		H18
CG42A	2024	T3
		T4[f]
CS41A	2014	T4[b]
		T6[d]
G1A	5050	O
		H34
		H38
GR20A	5052	O
		H34
		H38
GR40A	5154	O
		H34
		H38
GS10A	6063	T42
		T5
		T6
GS11A	6061	T4
		T6
		T62
GS11C	6062	T4
		T6
		T62
M1A	3003	O
		H112
		H14
		H18
Clad M1A	Alclad 3003	O
		H112
		H14
		H18
MG11A	3004	O
		H34
		H38

For alloy GS10A for -T6 temper revise value under column headed "Tensile Strength min, psi" from "32,000" to "30,000."

Table III.—Revise the table under Footnote *a* of Table III to include AA alloy designations. The revised table will appear as shown in the accompanying Table DD.

TABLE DD.—CONVERSION FACTORS.
(Revision of footnote [a], Table III, B 274.)

Alloy		Conversion Factor
ASTM	AA	
996A	1160	1.00
CG42A	2024	1.02
CS41A	2014	1.03
G1A	5050	0.99
GR20A	5052	0.99
GR40A	5154	0.98
GS10A	6063	1.00
GS11A	6061	1.00
GS11C	6062	1.00
M1A	3003	1.01
Clad M1A	Alclad 3003	1.01
MG11A	3004	1.00

Section 12(*a*).—Renumber as Section 13(*a*) and revise to read: "Diameter of pipe shall not vary from nominal diameter as given in III by an amount greater than the values shown in Table IV."

New Table.—Add a new Table IV as shown in the accompanying Table EE.

Table IV.—Renumber as Table V, and revise the last line in the first column from "12 to 12¼, incl" to "12 to 12⅞, incl."

Table V.—Renumber as Table VI, and revise to read as shown in the accompanying Table FF.

Revisions of Standards, Immediate Adoption

The committee recommends that the following two standard specifications be revised for immediate adoption as indicated below:

Standard Specifications for Magnesium Ingot and Stick for Remelting (B 92 - 52):[2]

New Section.—Add a new Section 2 titled "Basis of Purchase" and renumber all succeeding sections. The new Section 2 shall read:

2. Orders for ingot and stick under these specifications shall include the following information:

(*1*) Quantity in pieces or pounds, and
(*2*) Form (Section 1, Note).

Standard Specifications for Aluminum-Base Alloys in Ingot Form for Sand Castings, Die Castings and Permanent Mold Castings (B 179 - 53):[2]

Table I.—Revise to read as shown in the accompanying Table GG. All other notes remain unchanged.

TABLE EE.—PERMISSIBLE VARIATIONS IN OUTSIDE DIAMETER OF PIPE.
(New Table IV, B 274.)

Pipe Size, in.	Permissible Variations in Outside Diameter from the Nominal Diameter,[a] in.			
	Schedule 5 and 10		Schedule 20 and Heavier	
Under 2	+0.015	−0.031	+0.015	−0.031
2 to 4	+0.031	−0.031	+1 per cent	−1 per cent
4½ to 7	+0.062	−0.031	+1 per cent	−1 per cent
8 to 12	+0.093	−0.031	+1 per cent	−1 per cent

[a] Nominal diameters are as shown in Table III.

TABLE FF.—PERMISSIBLE VARIATIONS IN WALL THICKNESS FOR TUBE.
(Revision of Table V, B 274.)

Specified Wall Thickness,[a] in.	Permissible Variations in Wall Thickness,[b] ±, in.				
	Mean Wall Thickness[c] from Specified Wall Thickness				Wall Thickness at Any Point from Mean Wall Thickness (Eccentricity)
	Outside Diameter, in.				
	Under 1¼	1¼ to 3, excl	3 to 5, excl	5 and over	
Under 0.047	0.006	...	...	...	10 per cent of the mean wall thickness; maximum of 0.060 in., minimum of 0.010 in.
0.047 to 0.061	0.007	0.008	0.008	0.010	
0.062 to 0.077	0.008	0.008	0.009	0.012	
0.078 to 0.124	0.009	0.009	0.010	0.015	
0.125 to 0.249	0.009	0.009	0.013	0.020	
0.250 to 0.374	0.011	0.011	0.016	0.025	
0.375 to 0.499	...	0.015	0.021	0.035	
0.500 to 0.749	...	0.020	0.028	0.045	
0.750 to 0.999	...	...	0.035	0.055	
1.000 to 1.499	...	...	0.045	0.065	
1.500 to 2.000	...	...	...	0.075	

[a] When dimensions specified are outside and inside, rather than wall thickness itself, allowable deviation at any point (eccentricity) is ±10 per cent of the mean wall thickness; maximum ±0.060 in., minimum ±0.010 in.

[b] When outside diameter, inside diameter, and wall thickness are all specified, standard tolerances are applicable to any two of these dimensions, but not to all three.

[c] The "mean wall thickness" is determined by the average of two measurements taken opposite each other.

TABLE GG.—CHEMICAL REQUIREMENTS.
(Revision of Table I, B 179.)

Alloy[a, e]	Aluminum, per cent	Copper, per cent	Iron, per cent	Silicon, per cent	Manganese, per cent	Magnesium, per cent	Zinc, per cent	Chromium, per cent	Titanium, per cent	Nickel, per cent	Tin, per cent	Other Elements, per cent	
												Each	Total
CG100A	remainder	9.2 to 10.8	1.2	2.0	0.50	0.20 to 0.35	0.8	...	0.25	0.50	...	...	0.35
CN42A	remainder	3.5 to 4.5	0.8	0.7	0.35	1.3 to 1.8	0.35	0.25	0.25	1.7 to 2.3	...	0.05	0.15
C4A	remainder	4.0 to 5.0	0.8	0.50 to 1.5	0.35	0.03	0.35	...	0.25	...	...	0.05	0.15
CS42A	remainder	4.0 to 5.0	1.0	2.0 to 3.0	0.35	0.05	0.50	...	0.25	0.35	...	...	0.35
CS43A	remainder	3.5 to 4.5	1.0	2.5 to 3.5	0.50	0.05	1.0	...	0.25	0.35	...	...	0.50
CS66A	remainder	5.5 to 7.5	1.2	5.0 to 6.0	0.8	0.25 to 0.40	0.8	...	0.25	...	...	...	0.8
CS72A	remainder	6.0 to 8.0	1.2	1.0 to 4.0	0.6	0.10	2.5	...	0.25	0.35	...	...	0.50
CS104A	remainder	9.0 to 11.0	1.2	3.5 to 4.5	0.6	0.20 to 0.35	1.5	...	0.25	1.0	...	...	0.50
G4A	remainder	0.15	0.45	0.35	0.35	3.6 to 4.5	0.15	...	0.25	...	...	0.05	0.15
G8A	remainder	0.25	0.8	0.35	0.35	7.6 to 8.5	0.15	...	...	0.15	0.15	...	0.25
G10A	remainder	0.25	0.20	0.25	0.15	9.6 to 10.6	0.15	...	0.25	...	...	0.05	0.15
GS42A	remainder	0.35[b]	0.50[b]	1.4 to 2.2	0.8[b]	3.6 to 4.5	0.35	0.25	0.25	...	...	0.05	0.15
GZ42A	remainder	0.35	0.50	0.35	0.8	3.6 to 4.5	1.4 to 2.2	...	0.25	...	...	0.05	0.15
S5A	remainder	0.15	0.6	4.5 to 6.0	0.35	0.05	0.35	...	0.25	...	...	0.05	...
S5B	remainder	0.6	0.6	4.5 to 6.0	0.50	0.05	0.50	0.25	0.25	...	...	...	0.35
S5C	remainder	0.6	1.0	4.5 to 6.0	0.35	0.10	0.35	...	...	0.50	0.15	...	0.25
S12A-B	remainder	0.6	0.8	11.0 to 13.0	0.35	0.10	0.35	...	...	0.50	0.15	...	0.25
SC51A	remainder	1.0 to 1.5	0.6[d]	4.5 to 5.5	0.50[d]	0.45 to 0.6	0.35	0.25	0.25	...	...	0.05	0.15
SC54A-B	remainder	3.0 to 4.0	1.0	4.5 to 5.5	0.50	0.10	0.9	...	...	0.50	0.35	...	0.50
SC64A	remainder	4.0 to 5.0	0.8	5.0 to 6.0	0.50	0.10	1.0	...	0.25	...	...	...	0.50
SC64B	remainder	3.3 to 4.3	0.8	5.5 to 7.0	0.50	0.10	1.0	...	0.25	0.35	...	...	0.50
SC64C	remainder	3.0 to 4.5	1.0	5.5 to 7.0	0.8	0.50	1.0	...	0.25	0.50	...	...	0.50
SC82A	remainder	1.0 to 2.0	0.8	7.0 to 8.6	0.20 to 0.6	0.25 to 0.6	1.5	0.35	0.25	0.25	...	...	0.50
SC84A-B	remainder	3.0 to 4.0	1.0	7.5 to 9.5	0.50	0.10	0.9	...	...	0.50	0.35	...	0.50
SC122A	remainder	1.0 to 2.0	0.7	11.0 to 13.0	0.50 to 0.9	0.45 to 1.0	1.0	...	0.25	0.05	...	...	0.50
SG70A	remainder	0.25	0.50	6.5 to 7.5	0.35	0.25 to 0.40	0.35	...	0.25	...	...	0.05	0.15
SG100A-B	remainder	0.6	0.8	9.0 to 10.0	0.35	0.45 to 0.6	0.35	...	...	0.50	0.15	...	0.25
SN122A	remainder	0.50 to 1.5	1.0	11.0 to 13.0	0.35	0.9 to 1.3	0.35	...	0.25	2.0 to 3.0	...	0.05	...

ZC60A	remainder	0.35 to 0.65	1.3	0.35	0.05	0.25 to 0.45	6.0 to 7.0	...	0.25	...	...0.05	0.15
ZC81A-B	remainder	0.40 to 1.0	0.9	0.25	0.6	0.25 to 0.50	7.0 to 8.0	0.35	0.25	0.15	...0.05	0.25
ZG32A	remainder	0.20	0.6	0.20	0.40 to 0.6	1.4 to 1.8	2.7 to 3.3	0.20 to 0.40	0.25	...	...0.05	...
ZG42A	remainder	0.20	0.6	0.20	0.40 to 0.6	1.8 to 2.4	4.0 to 4.5	0.20 to 0.40	0.25	...	...0.05	...
ZG61A	remainder	0.30	0.8	0.25	0.30	0.50 to 0.65	5.2 to 6.0	0.40 to 0.6	0.10 to 0.25	...	...0.05	0.25
ZG61B	remainder	0.35 to 0.65	0.45	0.15	0.05	0.6 to 0.8	6.0 to 7.0	...	0.25	...	...0.05	0.15

[a] Certain of these alloys formerly were designated as follows:

Present Designation	Former Designation	Present Designation	Former Designation	Present Designation	Former Designation	Present Designation	Former Designation
CG100A	CG1	G4A	G1	S12A-B	S5, S9	SC84A	SC6
CN42A	CN21	G8A	G2	SC51A	SC21	SC84B	SC7
C4A	C1	G10A	G3	SC54A	SC2	SC122A	SC41
CS42A	CS4	GS42A	GS1	SC54B	SC5	SG70A	SG1
CS43A	CS5	GZ42A	GZ1	SC64A	SC1	SG100A-B	SG2, SG3
CS66A	CS23	S5A	S1	SC64B	SC8	SN122A	SN41
CS72A	CS22	S5B	S2	SC64C	SC9	ZG61A	ZG41
CS104A	CS21	S5C	S4	SC82A	SC42		

[b] If the copper content plus the iron content exceeds 0.50 per cent, a manganese content of at least 0.35 per cent is desirable.

[c] For cooking utensils copper may be specified by the purchaser at 0.30 per cent, max.

[d] If the iron content exceeds 0.45 per cent, it is desirable to have manganese present in an amount equal to one-half the iron.

[e] These alloy designations were established in accordance with the Tentative Recommended Practice for Codification of Light Metals and Alloys, Cast and Wrought (ASTM Designations B 275).[1]

NOTE 1.—Where single units are shown, these indicate the maximum amounts permitted.

NOTE 2.—Analysis shall regularly be made only for the elements specifically mentioned in this table. If, however, the presence of other elements is suspected, or indicated in the course of routine analysis, further analysis shall be made to determine that the total of these other elements is not present in excess of the limits specified in the last column of the table.

NOTE 3.—The following applies to all specified limits in this table: For purposes of acceptance or rejection, an observed value or a calculated value obtained from analysis should be rounded off to the nearest unit in the last right-hand place of figures used in expressing the specified limit.

APPENDIX II

ATMOSPHERIC EXPOSURE OF WROUGHT ALUMINUM AND MAGNESIUM ALLOYS

By L. H. Adam[1]

Fourteen years ago, a study of the effects of the atmospheric exposure of light metals exposed for 10 yr at various seacoast and industrial test stations was completed. These data were presented by E. H. Dix, Jr. and R. B. Mears at the Pittsburgh Meeting of the Society in 1946.[2] In the meantime, new aluminum and magnesium alloys and fabrication techniques were developed. It was deemed advisable to canvass industry on the desirability of additional studies with the new alloys. Committee B-7 on Light Metals and Alloys undertook a program which, although not all inclusive, was within the realm of its capability. The program was outlined to the Society in 1953.[3]

Both wrought and cast materials were included in the original program, and the data collected will be made part of the official records by periodic reports to the committee. The 1954 report was on cast alloys.[4] The present data cover results obtained on wrought alloy specimens exposed for 1 yr at the industrial site located on the Port Authority Building in the center of New York City, the rural site at State College, Pa., and the East Coast Site, 800 ft from the ocean at Kure Beach, N. C. In the near future, data obtained on specimens exposed at the West Coast site at Point Reyes, and the Gulf Coast site at Freeport, Tex., will be reported. Due to the delays in having these sites erected, the tests were not started in sufficient time to be included in the present report.

The twelve aluminum and four magnesium alloys listed in Tables I and II were evaluated on the basis of tension specimens taken from 0.064-in. thick sheet and 0.25-in. plate. These data are shown in Tables III to XXVII inclusive for aluminum alloys, and Tables XXVIII to XXX for magnesium alloys. The sheet and plate material had standard specimens[5] cut from the individual exposed specimens, whereas the welded and riveted specimens had tension specimens prepared as shown in Figs. 1 to 4. The latter specimens had only a breaking load reported.

The data summarized for review and information in the form of bar graphs, Figs. 5 to 9 inclusive, present specifica-

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[1] Materials Engineer, Frankford Arsenal, Pitman-Dunn Labs., Philadelphia, Pa.

[2] E. H. Dix, Jr. and R. B. Mears, "The Resistance of Aluminum-Base Alloys to Atmospheric Exposure," Symposium on Atmospheric Exposure Tests on Non-Ferrous Metals, Am. Soc. Testing Mats., p. 57 (1946). (Issued as separate publication *ASTM STP No. 67*.)

[3] Appendix to Report of Committee B-7 on Light Metals and Alloys, Cast and Wrought, *Proceedings*, Am. Soc. Testing Mats., Vol. 53, p. 227 (1953).

[4] Appendix to Report of Committee B-7 on Light Metals and Alloys, Cast and Wrought, *Proceedings*, Am. Soc. Testing Mats., Vol. 54, p. 263 (1954).

[5] Tentative Method of Tension Testing of Metallic Material (E 8 – 52 T), 1952 Book of ASTM Standards, Part 1, p. 1389; Part 2, p. 1208.

TABLE I.—CHEMICAL ANALYSES OF MAGNESIUM ALLOYS USED IN THE 10-YR ATMOSPHERIC EXPOSURE PROGRAM SPONSORED BY ASTM COMMITTEE B-7.

Magnesium Alloy Designations			Chemical Composition, per cent				
Commercial	ASTM		Aluminum	Manganese, min	Magnesium	Zinc	Zirconium, min
Sheet 0.064 in. Plate 0.025 in.[a]							
M	M1A	ASTM Spec.		1.20	Remainder		
	Sheet	As rec'd values		1.59	Remainder		
FS-1	AZ31A	ASTM Spec.	2.5 to 3.5		Remainder	0.6 to 1.4	
	Sheet	As rec'd values	3.00		Remainder	1.13	
	Plate	As rec'd values	2.95		Remainder	1.03	
Extruded Bar 0.25 in.[b]							
M	M1A	ASTM Spec.		1.20	Remainder		
	Extruded Bar	As rec'd values		1.76	Remainder		
FS-1	AZ31B	ASTM Spec.	2.5 to 3.5		Remainder	0.6 to 1.4	
	Extruded Bar	As rec'd values	3.39		Remainder	1.09	
AMC.-585	AZ80A	ASTM Spec.	7.8 to 9.2		Remainder	0.2 to 0.8	
	Extruded Bar	As rec'd values	8.22		Remainder	0.45	
ZK60	ZK60A	ASTM Spec.			Remainder	4.8 to 6.2	0.45
	Extruded Bar	As rec'd values			Remainder	5.58	0.60

[a] Sheet: Tentative Specification for Magnesium-Base Alloy Sheet (B 90 – 51 T), 1952 Book of ASTM Standards, Part 2, p. 533.

[b] Extruded Bar: Tentative Specification for Magnesium-Base Alloy Bars, Rods, and Shapes (B 107 – 53 T), 1953 Supplement to Book of ASTM Standards, Part 2, p. 134.

tion limits, condition of specimens prior to exposure, and after being maintained under controlled conditions in sealed airtight containers. Significant changes are:

1. With the aluminum alloys, the decreases in strength are obscured by the increases due to natural aging of the alloys. Any loss due to exposure was often less than the increase due to aging. The specimens exposed at the industrial site reflected the greatest average loss. However, any decrease was less than 5 per cent of the original strength. Except for ZG62A-T6, the spot-welded aluminum specimens showed strength losses of less than 10 per cent. The latter alloy indicated approximately 30 per cent loss in strength.

2. The magnesium alloys had less than 5 per cent loss in strength due to the 1-yr exposure. However, the effect of the exposure was definitely apparent in the changes in ductility of the alloy. Although the surfaces of all specimens were badly corroded, the spot-welded and riveted magnesium alloy specimens cut from the plate were as strong in tension as the originally unexposed specimens.

Acknowledgment:

The present extensive program has been made possible by the excellent cooperation of the participating members of the Society. Specific mention should be given to U. S. Naval Experimental Station, Annapolis, Bell Telephone Laboratories, Inc., Aluminum Company of

TABLE II.—CHEMICAL ANALYSES OF ALUMINUM ALLOYS USED IN THE 10-YR ATMOSPHERIC EXPOSURE PROGRAM SPONSORED BY ASTM COMMITTEE B-7.

Aluminum Alloy Designations			Chemical Composition, per cent											
Commercial	ASTM		Aluminum	Copper	Iron	Silicon	Manganese	Magnesium	Zinc	Chromium	Titanium	Nickel	Others	
Sheet 0.064 in. Plate 0.25 in.[a]													Each	Total
3003	M1A	ASTM Spec.	Remainder	0.20	0.7	0.6	1.0 to 1.5		0.10				0.05	0.15
	Sheet	As rec'd values	Remainder	0.12	0.37	0.09	1.07	<0.01	<0.01	<0.01		<0.01		
5052	GR20A	ASTM Spec.	Remainder	0.10	[b]	[b]	0.10	2.2 to 2.8	0.20	0.15 to 0.35			0.05	0.15
	Sheet	As rec'd values	Remainder	<0.05	0.17	0.05	<0.01	2.50	<0.03	<0.25	0.01	<0.01		
6061	GS11A	ASTM Spec.	Remainder	0.15 to 0.40	0.7	0.40 to 0.8	0.15	0.8 to 1.2	0.20	0.15 to 0.35	0.15		0.05	0.15
	Sheet	As rec'd values	Remainder	0.20	0.30	0.49	0.02	0.84	0.01	0.27	<0.01	<0.01		
	Plate	As rec'd values	Remainder	0.26	0.31	0.54	<0.01	0.89	<0.05	0.22	<0.01	<0.01		
2024	CG42A	ASTM Spec.	Remainder	3.8 to 4.9	0.50	0.50	0.30 to 0.9	1.2 to 1.8	0.10	0.25			0.05	0.15
	Sheet	As rec'd values	Remainder	4.25	0.42	0.21	0.54	1.33	0.05	0.06		<0.01		
7075	ZG62A	ASTM Spec.	Remainder	1.2 to 2.0	0.7	0.50	0.30	2.1 to 2.9	5.1 to 6.1	0.18 to 0.40	0.20		0.05	0.15
	Sheet	As rec'd values	Remainder	1.23	0.24	0.10	0.13	2.33	5.76	0.25	0.03	0.04		
3004	MG11A	ASTM Spec.	Remainder	0.20	0.7	0.30	1.0 to 1.5	0.8 to 1.3	0.10				0.05	0.15
	Sheet	As rec'd values	Remainder	0.11	0.49	0.10	1.07	0.96	0.10			0.01		
5050	G1A	ASTM Spec.	Remainder	0.25	0.8	0.50	0.15	1.0 to 1.8	0.25	0.10			0.05	0.15
	Sheet	As rec'd values	Remainder	0.04	0.43	0.19	0.04	1.25	0.03	<0.01		<0.01		
2014	CS41A	ASTM Spec.	No Requirement											
	Plate T4	As rec'd values	Remainder	4.49	0.42	0.89	0.87	0.33	0.05	0.07	<0.01			
	Plate T6	As rec'd values	Remainder	4.62	0.45	0.94	0.89	0.34	0.05	0.07	<0.01	<0.01		

Alclad														
2014	CS41A	ASTM Spec.	Remainder	3.9 to 5.0	1.0	0.50 to 1.2	0.40 to 1.2	0.20 to 0.8	0.25	0.25	0.15		0.05	0.15
	Sheet	As rec'd values	Remainder	4.01	0.33	0.66	0.56	0.53	0.04	<0.01		<0.01		
	Plate	As rec'd values	Remainder	4.60	0.37	0.72	0.83	0.38	<0.01	<0.02		<0.01		
Alclad	CG42A	ASTM Spec.	Remainder	3.8 to 4.9	0.50	0.50	0.30 to 0.9	1.2 to 1.8	0.10	0.25			0.05	0.15
2024	Sheet	As rec'd values	Remainder	4.07	0.28	0.14	0.48	1.41	0.07	0.01		<0.01		
	Plate	As rec'd values	Remainder	3.98	0.37	0.14	0.61	1.27	0.01	<0.02		<0.01		
Alclad	ZG62A	ASTM Spec.	Remainder	1.2 to 2.0	0.7	0.50	0.30	2.1 to 2.9	5.1 to 6.1	0.18 to 0.40	0.20		0.05	0.15
7075	Sheet	As rec'd values	Remainder	1.42	0.24	0.12	0.11	2.21	5.58	0.26	0.07			
	Plate	As rec'd values	Remainder	1.31	0.29	0.07	0.21	2.41	5.83	0.26	0.04			
Extruded Bar 0.25 in.[c]														
6061	GS11A	ASTM Spec.	Remainder	0.15 to 0.40	0.7	0.40 to 0.8	0.15	0.8 to 1.2	0.20	0.15 to 0.35	0.15		0.05	0.15
	Extruded Bar	As Rec'd Values	Remainder	0.29	0.22	0.52	0.07	0.99	<0.01	0.29	<0.01	<0.01		
6063	GS10A	ASTM Spec.	Remainder	0.10	0.50	0.20 to 0.6	0.10	0.45 to 0.9	0.10	0.10	0.10		0.05	0.15
	Extruded Bar	As rec'd values	Remainder	<0.05	0.16	0.28	0.01	0.58	0.01	0.01	<0.01	<0.01		
2014	CS41A	ASTM Spec.	Remainder	3.9 to 5.0	1.0	0.50 to 1.2	0.40 to 1.2	0.20 to 0.8	0.25	0.10	0.15		0.05	0.15
	Extruded Bar T4	As rec'd values	Remainder	4.23	0.42	0.77	0.76	0.32	<0.01	0.02	<0.01	<0.01		
	Extruded Bar T6	As rec'd values	Remainder	4.12	0.42	0.82	0.74	0.31	0.05	0.01	0.02	<0.01		
7075	ZG62A	ASTM Spec.	Remainder	1.2 to 2.0	0.7	0.50	0.30	2.1 to 2.9	5.1 to 6.1	0.18 to 0.40	0.20		0.05	0.15
	Extruded Bar	As rec'd values	Remainder	1.27	0.32	0.12	0.11	2.46	5.89	0.26	0.07	0.05		

NOTE: Single units shown in ASTM Specifications indicate the maximum amount permitted.

[a] Sheet and Plate: Tentative Specifications for Aluminum and Aluminum Sheet and Plate (B 209 – 53 T), 1953 Supplement to Book of ASTM Standards, Part 2, p. 146.

[b] The permissible maximum amount of iron plus silicon is 0.45 per cent.

[c] Extruded Bar: Tentative Specifications for Aluminum and Aluminum-Alloy Extruded Bars, Rods, and Shapes (B 221 – 53 T), 1953 Supplement to Book of ASTM Standards, Part 2, p. 169.

America, International Nickel Co., Dow Chemical Co., Reynolds Metals Co., and staff members of the Pitman-Dunn Laboratories, Frankford Arsenal.

The continued interest in this program has made it successful, and the data obtained should add to our knowledge on the performance of light alloys.

TABLE III.—DATA ON ALUMINUM ALLOY NO. M1A-H14 (0.064-IN. SHEET, PANEL).

ASTM Specification Requirements[a]	As Received	Control	6-month Exposure			1-yr Exposure		
			State College	New York	Kure Beach	State College	New York	Kure Beach
Yield Strength, 0.2 per cent Offset, psi								
No Requirements	20 300	21 300	21 600	21 600	21 700	22 000	20 600	21 600
	20 400	21 900	21 600	21 500	22 000	21 900	20 200	22 300
	20 100	21 100	21 900	21 900	21 500	22 200	20 600	21 900
	20 300	21 900	20 600	21 900	21 500	21 900	20 600	21 200
Average	20 300	21 600	21 400	21 700	21 700	22 000	20 500	21 800
Tensile Strength, psi								
20 000 psi, min	21 900	22 200	23 100	22 000	22 500	22 700	21 500	22 700
	21 600	23 100	23 100	22 500	22 500	22 700	21 600	22 500
	21 400	22 700	22 600	22 200	22 600	22 800	22 200	22 900
	21 500	22 300	22 900	22 900	22 600	22 600	21 800	22 500
Average	21 600	22 600	22 900	22 400	22 600	22 700	21 800	22 700
Elongation in 2 in., Per Cent								
5.0 per cent, min	6.5	6.0	5.0	3.5[c]	7.0	8.0	6.0	8.0
	3.5[b,c]	6.0	5.0	6.0	9.0	8.0	6.0	6.0
	7.5	6.0	5.5	6.5	9.0	8.0	6.0	6.0
	7.5	6.0	6.0	7.0	8.5	7.0	6.0	6.0
Average	6.3	6.0	5.4	5.6	8.4	7.8	6.0	6.5

[a] Tentative Specification for Aluminum and Aluminum Sheet and Plate (B 209 – 53 T), 1953 Supplement to Book of ASTM Standards, Part 2, p. 146.

[b] Broke outside gage marks.

[c] Low.

TABLE IV.—DATA ON ALUMINUM ALLOY NO. GR20A-H34 (0.064-IN. SHEET, PANEL).

ASTM Specification Requirements	As Received	Control	6-month Exposure			1-yr Exposure		
			State College	New York	Kure Beach	State College	New York	Kure Beach
YIELD STRENGTH, 0.2 PER CENT OFFSET, PSI								
No Requirement	26 600	28 100	28 800	no sample	28 800	28 300	27 700	28 300
	26 600	27 800	28 600		28 700	28 300	27 400	28 300
	26 700	28 000	28 700		28 700	28 300	28 600	28 300
	26 000	28 000	28 400		28 700	28 300	28 900	....
Average	26 500	28 000	28 600		28 700	28 300	28 200	28 300
TENSILE STRENGTH, PSI								
34 000 psi, min	34 000	35 300	36 500		35 900	35 000	34 400	35 000
	33 300[a]	35 100	36 900		35 700	35 000	34 400	34 600
	33 800[a]	34 800	36 700		35 800	34 800	34 400	34 800
	33 400[a]	34 400	36 000		35 400	34 800	34 400	....
Average	33 600[a]	34 900	36 500		35 700	34 900	34 400	34 800
ELONGATION IN 2 IN., PER CENT								
6 per cent, min	9.0	10.0	10.0		10.0	10.0	10.0	10.0
	9.0	10.0	10.0		10.0	10.0	10.0	10.0
	10.5	10.0	10.0		10.5	10.0	9.0	10.0
	9.5	10.0	10.0		8.0	10.0	10.0	....
Average	9.5	10.0	10.0		9.6	10.0	9.8	10.0

[a] Low.

TABLE V.—DATA ON ALUMINUM ALLOY NO. GS11A-T6 (0.064-IN. SHEET, PANEL).

ASTM Specification Requirements	As Received	Control	6-month Exposure			1-yr Exposure		
			State College	New York	Kure Beach	State College	New York	Kure Beach
YIELD STRENGTH, 0.2 PER CENT OFFSET, PSI								
35 000 psi, min	39 100	43 100	44 600	no sample	44 400	41 900	40 600	41 300
	38 600	43 300	43 800		43 000	41 200	41 200	41 300
	38 200	43 200	44 700		43 000	41 800	40 500	41 300
	38 200	43 500	45 000		43 200	42 000	40 600	41 600
Average	38 500	43 300	44 500		42 900	41 700	40 700	41 400
TENSILE STRENGTH, PSI								
42 000 psi, min	45 100	47 200	47 200		46 500	46 200	45 800	46 800
	45 000	47 200	47 100		45 600	45 800	45 600	46 500
	45 300	47 300	47 300		47 800	46 300	45 500	46 800
	45 000	47 500	48 300		46 700	46 400	45 800	46 700
Average	45 100	47 300	47 500		46 700	46 200	45 700	46 700
ELONGATION IN 2 IN., PER CENT								
10.0 per cent, min	15.0	12.0	10.5		12.5	12.0	12.0	12.0
	15.0	10.0	11.5		12.5	12.0	12.0	12.0
	16.0	12.0	10.0		11.5	12.0	12.0	13.0
	15.5	10.0	11.5		12.0	12.0	12.0	12.0
Average	15.4	11.0	10.9		12.1	12.0	12.0	12.3

TABLE VI.—DATA ON ALUMINUM ALLOY NO. CG42A-T3 (0.064-IN. SHEET, PANEL).

ASTM Specification Requirements	As Received	Control	6-month Exposure			1-yr Exposure		
			State College	New York	Kure Beach	State College	New York	Kure Beach
YIELD STRENGTH, 0.2 PER CENT OFFSET, PSI								
42 000 psi, min	45 200	48 200	50 800	46 800	49 700	48 500	46 300	46 500
	45 500	47 700	51 000	47 100	50 300	48 400	46 200	46 500
	45 000	48 400	51 500	46 700	50 800	49 700	47 000	46 200
	46 300	48 500	51 500	47 000	51 800	49 500	46 800	....
Average	45 500	48 200	51 200	46 900	50 700	49 000	46 600	46 00
TENSILE STRENGTH, PSI								
64 000 psi, min	66 800	69 800	71 900	67 100	70 600	71 700	65 100	68 300
	66 000	69 500	71 400	67 600	70 500	69 900	59 000[b]	68 100
	67 000	69 800	71 700	68 300	70 800	70 000	65 500	66 800
	66 600	70 100	71 800	68 300	70 900	69 700	66 600	....
Average	66 600	69 800	71 700	67 800	70 700	70 300	64 100	67 700
ELONGATION IN 2 IN., PER CENT								
17.0 per cent, min	18.0	20.0	17.5	17.5	18.0	19.0	11.0[b]	16.0[b]
	18.0	20.0	19.0	17.5	17.0	19.0	[a]	17.0
	19.0	20.0	19.0	18.0	17.5	19.0	14.0[b]	16.0[b]
	18.5	19.0	19.0	18.0	[a]	19.0	14.0[b]	...
Average	18.4	19.8	18.6	17.8	17.5	19.0	13.0[b]	16.3[b]

[a] Broke outside gage marks.

[b] Low.

TABLE VII.—DATA ON ALUMINUM ALLOY NO. ZG62A-T6 (0.064-IN. SHEET, PANE

ASTM Specification Requirements	As Received	Control	6-month Exposure			1-yr Exposure		
			State College	New York	Kure Beach	State College	New York	Kure Beach
YIELD STRENGTH, 0.2 PER CENT OFFSET, PSI								
66 000 psi, min	68 400	72 000	72 900	71 500	72 500	70 200	70 100	71 700
	68 100	72 400	72 900	71 700	72 500	69 800	70 900	71 300
	67 900	72 200	73 500	72 400	71 900	71 200	....	....
	67 700	72 500	73 100	72 300	72 500	71 800	....	....
Average	68 000	72 300	73 100	72 000	72 400	70 800	70 500	71 500
TENSILE STRENGTH, PSI								
77 000 psi, min	78 000	80 800	82 500	80 700	81 700	79 800	79 200	81 200
	78 100	80 500	82 500	80 500	81 600	79 900	80 400	81 200
	78 600	80 700	82 300	80 900	80 900	80 200	79 600	80 900
	78 800	80 800	82 200	80 500	80 900	80 100	79 700	80 900
Average	78 400	80 700	82 400	80 700	81 300	80 100	79 700	81 100
ELONGATION IN 2 IN., PER CENT								
8.0 per cent, min	11.0	10.0	9.5	7.5[a]	10.5	10.0	9.0	10.0
	10.0	10.0	9.5	9.0	11.0	10.0	10.0	11.0
	10.5	10.0	9.0	8.0	11.5	10.0	8.0	10.0
	11.0	10.0	9.0	9.5	11.0	10.0	8.0	10.0
Average	10.6	10.0	9.3	8.5	11.0	10.0	8.8	10.3

[a] Low.

TABLE VIII.—DATA ON ALUMINUM ALLOY NO. MG11A-H34 (0.064-IN. SHEET, PANEL).

ASTM Specification Requirements	As Received	Control	6-month Exposure			1-yr Exposure		
			State College	New York	Kure Beach	State College	New York	Kure Beach
YIELD STRENGTH, 0.2 PER CENT OFFSET, PSI								
No Requirement	30 200	32 100	32 700	31 400	32 500	32 000	31 600	33 100
	30 300	32 100	32 100	31 800	32 300	31 900	31 700	32 300
	30 300	32 200	32 700	31 900	32 400	31 800	32 200	32 500
	30 000	32 100	32 600	32 300	32 400	31 900	32 200	32 900
Average	30 200	32 100	32 500	31 900	32 400	31 900	31 900	32 700
TENSILE STRENGTH, PSI								
32 000 psi, min	34 600	36 900	36 800	37 000	36 900	36 700	36 200	37 600
	34 500	37 000	36 500	37 200	36 500	36 700	36 200	37 300
	34 800	36 800	36 600	36 600	36 800	36 700	36 100	37 600
	34 500	36 700	36 600	36 900	36 800	36 600	36 100	37 300
Average	34 600	36 900	36 600	36 900	36 800	36 700	36 200	37 500
ELONGATION IN 2 IN., PER CENT								
4.0 per cent, min	9.0	8.0	8.5	7.5	8.5	8.0	8.0	8.0
	8.0	8.0	8.5	7.5	9.0	8.0	8.0	8.0
	8.0	8.0	9.0	7.5	9.5	8.0	8.0	8.0
	8.0	8.0	9.0	7.0	10.0	8.0	8.0	8.0
Average	8.3	8.0	8.8	7.4	9.3	8.0	8.0	8.0

TABLE IX.—DATA ON ALUMINUM ALLOY NO. G1A-H34 (0.064-IN. SHEET, PANEL).

ASTM Specification Requirements	As Received	Control	6-month Exposure			1-yr Exposure		
			State College	New York	Kure Beach	State College	New York	Kure Beach
YIELD STRENGTH, 0.2 PER CENT OFFSET, PSI								
No Requirement	22 500	24 200	24 500	23 700	24 300	23 500	23 500	23 800
	22 500	24 200	23 900	23 700	24 600	24 600	24 500	23 200
	22 500	24 700	24 600	24 200	24 600	24 200	25 100	23 900
	22 700	24 800	24 600	24 200	24 600	24 600	25 500	24 100
Average	22 600	24 500	24 400	24 000	24 500	24 200	24 700	23 800
TENSILE STRENGTH, PSI								
25 000 psi, min	26 100	27 400	27 700	27 100	27 500	27 600	26 800	27 100
	26 000	27 500	27 700	27 100	27 800	27 500	26 900	27 100
	26 700	27 200	28 100	27 200	27 800	27 200	27 100	27 200
	26 200	27 400	27 900	27 700	27 800	27 400	27 200	27 300
Average	26 300	27 400	27 900	27 300	27 700	27 400	27 000	27 200
ELONGATION IN 2 IN., PER CENT								
5.0 per cent, min	8.5	8.0	7.0	4.0[b]	7.5	8.0	7.0	8.0
	[a]	8.0	8.0	6.5	7.5	8.0	7.0	7.0
	8.5	8.0	7.5	6.5	7.0	7.0	7.0	8.0
	8.0	8.0	8.0	7.0	8.5	8.0	8.0	7.0
Average	8.3	8.0	7.6	6.0	7.6	7.8	7.3	7.5

[a] Broke outside of gage marks.

[b] Low.

TABLE X.—DATA ON ALUMINUM ALLOY NO. CS41A-T6 (0.064-IN. CLAD SHEET, PANEL).

ASTM Specification Requirements	As Received	Control	6-month Exposure			1-yr Exposure		
			State College	New York	Kure Beach	State College	New York	Kure Beach
YIELD STRENGTH, 0.2 PER CENT OFFSET, PSI								
57 000 psi, min	55 000[a]	60 100	60 500	59 400	55 300[a]	58 600	60 900	59 900
	56 500[a]	60 400	60 500	60 000	55 300[a]	59 200	60 900	59 300
	56 600[a]	59 600	60 800	60 300	56 000[a]	59 000	61 000	59 600
	56 500[a]	60 200	61 400	60 300	56 000[a]	59 400	60 700	59 600
Average	56 200[a]	60 100	60 800	60 000	55 700[a]	59 100	60 900	59 600
TENSILE STRENGTH, PSI								
64 000 psi, min	65 000	67 000	67 600	66 100	62 500[a]	66 000	67 500	66 700
	63 600[a]	67 100	67 500	66 400	62 400[a]	66 000	67 400	66 600
	63 900[a]	66 900	67 500	66 200[a]	62 500[a]	66 300	67 300	66 700
	63 600[a]	66 900	67 400	66 400	62 500[a]	66 300	67 300	66 500
Average	64 000	67 000	67 500	66 300	62 500[a]	66 200	67 400	66 600
ELONGATION IN 2 IN., PER CENT								
8.0 per cent, min	9.5	8.0	9.5	8.5	10.5	9.0	9.0	9.0
	9.0	8.0	9.0	8.5	10.5	9.0	9.0	9.0
	10.0	9.0	9.0	8.0	10.5	9.0	9.0	9.0
	10.5	10.0	9.0	8.0	10.5	10.0	9.0	9.0
Average	9.8	8.8	9.1	8.3	10.5	9.3	9.0	9.0

[a] Low.

TABLE XI.—DATA ON ALUMINUM ALLOY NO. CG42A-T3 (0.064-IN. CLAD SHEET, PANEL).

ASTM Specification Requirements	As Received	Control	6-month Exposure			1-yr Exposure		
			State College	New York	Kure Beach	State College	New York	Kure Beach
YIELD STRENGTH, 0.2 PER CENT OFFSET, PSI								
40 000 psi, min	42 700	47 100	47 900	46 900	45 500	45 800	45 600	46 300
	42 400	46 700	46 000	46 900	45 500	45 200	46 800	46 000
	42 700	48 400	46 000	46 900	45 500	44 900	45 100	46 300
	41 900	47 700	46 300	46 800	45 500	45 800	44 800	46 000
Average	42 400	47 500	46 600	46 900	45 500	45 400	45 600	46 200
TENSILE STRENGTH, PSI								
62 000 psi, min	63 200	67 700	68 200	68 400	67 700	66 900	66 400	68 400
	63 900	67 700	67 700	68 000	67 400	67 400	66 400	68 400
	64 000	68 300	67 600	68 200	67 700	67 000	66 700	67 800
	63 600	67 400	68 500	69 000	67 300	67 100	66 400	68 000
Average	63 700	67 800	68 000	68 400	67 500	67 100	66 500	68 200
ELONGATION IN 2 IN., PER CENT								
15.0 per cent, min	20.0	18.0	19.5	17.0	20.0	21.0	20.0	20.0
	19.0	18.0	19.0	16.0	20.0	20.0	20.0	19.0
	21.0	19.0	18.5	14.5[a]	18.5	21.0	20.0	19.0
	18.5	18.0	19.5	17.0	20.0	20.0	20.0	19.0
Average	19.6	18.3	19.1	16.1	19.6	20.5	20.0	19.3

[a] Low.

TABLE XII.—DATA ON ALUMINUM ALLOY NO. ZG62A-T6 (0.064-IN. CLAD SHEET, PANEL).

ASTM Specification Requirements	As Received	Control	6-month Exposure			1-yr Exposure		
			State College	New York	Kure Beach	State College	New York	Kure Beach
			Yield Strength, 0.2 per cent Offset, psi					
62 000 psi, min	65 100	No value	69 900	68 300	69 900	66 700	70 200	71 000
	64 700		69 400	68 800	69 900	69 900	68 600	69 800
	65 000		70 500	67 500	70 600	67 700	69 400	70 300
	65 900		70 500	61 600	69 600	66 000	68 600	69 200
Average	65 200		70 100	66 600	70 000	67 600	69 200	70 100
			Tensile Strength, psi					
72 000 psi, min	75 400	77 300	80 200	82 400	80 200	76 800	77 400	79 500
	75 500	77 100	80 000	79 400	80 200	75 200	78 000	78 300
	75 600	77 500	80 000	78 800	80 200	78 300	78 200	79 200
	75 500	77 000	80 000	75 600	80 100	77 600	77 900	78 500
Average	75 500	77 200	80 100	79 100	80 200	77 000	77 900	78 900
			Elongation in 2 in., Per Cent					
8.0 per cent, min.	11.0	10.0	12.0	11.0	12.5	12.0	10.0	10.0
	11.0	10.0	11.5	11.0	12.0	10.0	10.0	12.0
	8.0	9.0	11.0	11.0	12.0	12.0	10.0	12.0
	11.5	10.0	11.0	11.0	12.0	12.0	10.0	10.0
Average	10.4	9.8	11.4	11.0	12.1	11.5	10.0	11.0

TABLE XIII.—DATA ON ALUMINUM ALLOY NO. GS11A-T6 (0.25-IN. PLATE, PANEL).

ASTM Specification Requirements	As Received	Control	6-month Exposure			1-yr Exposure		
			State College	New York	Kure Beach	State College	New York	Kure Beach
			Yield Strength, 0.2 per cent Offset, psi					
35 000 psi, min	40 300	40 800	39 700	44 900	39 500	39 800	39 700	40 500
	40 700	40 400	39 300	45 500	39 800	39 800	40 200	40 200
	41 000	40 500	39 000	44 800	40 200	39 700	40 300	40 200
	40 600	40 300	39 400	45 300	40 200	39 700	40 300	40 200
Average	40 700	40 500	39 400	45 100	39 900	39 800	40 100	40 300
			Tensile Strength, psi					
42 000 psi, min	47 600	46 200	45 900	50 200	46 100	46 000	45 700	45 700
	47 600	46 200	45 900	50 200	46 000	46 000	46 000	45 900
	47 600	45 900	45 800	50 200	46 000	46 100	45 800	46 100
	48 400	45 900	45 800	50 000	45 900	46 200	45 800	45 600
Average	47 800	46 100	45 900	50 200	46 000	46 100	45 800	45 800
			Elongation in 2 in., Per Cent					
10.0 per cent, min	16.5	16.0	16.0	14.5	18.5	17.0	17.0	17.0
	16.5	16.0	16.5	15.5	18.5	17.0	17.0	17.0
	16.5	17.0	16.5	15.5	17.5	17.0	17.0	17.0
	17.5	17.0	16.5	16.0	17.5	17.0	17.0	17.0
Average	16.8	16.5	16.4	15.4	18.0	17.0	17.0	17.0

TABLE XIV.—DATA ON ALUMINUM ALLOY NO. CS41A-T4 (0.25-IN. PLATE, PANEL).

ASTM Specification Requirements	As Received	Control	6-month Exposure			1-yr Exposure		
			State College	New York	Kure Beach	State College	New York	Kure Beach
YIELD STRENGTH, 0.2 PER CENT OFFSET, PSI								
No Requirement	42 000	41 800	41 100	40 900	40 800	42 100	42 000	42 400
	42 000	41 900	41 100	40 900	40 500	42 200	41 700	42 000
	41 000	42 200	41 100	40 700	40 500	41 800	41 700	42 300
	41 200	42 000	41 000	41 100	40 600	41 800	42 700	42 300
Average	41 600	42 000	41 100	40 900	40 600	42 000	42 000	42 300
TENSILE STRENGTH, PSI								
No Requirement	66 200	65 600	63 700	63 100	63 600	65 800	65 600	66 200
	66 200	65 200	63 900	63 300	63 600	66 000	65 200	66 100
	66 300	65 700	63 800	63 100	63 900	65 600	65 400	66 000
	66 500	65 800	63 500	63 300	64 200	65 900	65 300	65 900
Average	66 300	65 600	63 700	63 200	63 800	65 800	65 400	66 100
ELONGATION IN 2 IN., PER CENT								
No Requirement	16.5	18.0	18.5	18.5	18.5	19.0	16.0	17.0
	18.0	12.0	18.5	17.5	16.5	19.0	16.0	17.0
	18.5	17.0	18.5	15.0	18.5	18.0	17.0	18.0
	19.5	26.0	19.0	15.0	19.0	19.0	17.0	17.0
Average	18.1	18.3	18.6	16.5	18.1	18.8	16.5	17.3

TABLE XV.—DATA ON ALUMINUM ALLOY NO. CS41A-T6 (0.25-IN. PLATE, PANEL).

ASTM Specification Requirements	As Received	Control	6-month Exposure			1-yr Exposure		
			State College	New York	Kure Beach	State College	New York	Kure Beach
YIELD STRENGTH, 0.2 PER CENT OFFSET, PSI								
No Requirement	62 500	63 700	63 200	63 700	62 700	63 100	63 100	62 200
	62 500	63 300	63 300	63 700	63 100	63 300	63 200	62 200
	62 400	63 200	63 400	63 700	63 000	63 300	63 100	63 100
	63 100	62 700	63 200	63 900	62 900	63 300	63 200	62 900
Average	62 600	63 200	63 300	63 800	62 900	63 300	63 200	62 600
TENSILE STRENGTH, PSI								
No Requirement	71 400	71 800	71 600	72 100	70 500	71 300	70 400	70 200
	71 600	72 900	71 600	71 800	70 500	71 200	71 100	70 300
	71 600	71 500	71 500	71 400	70 600	71 100	70 500	70 000
	71 800	71 000	71 600	71 400	70 500	71 300	70 500	70 200
Average	71 600	71 800	71 600	71 700	70 500	71 200	70 600	70 200
ELONGATION IN 2 IN., PER CENT								
No Requirement	10.5	9.0	9.0	6.5	9.5	9.0	9.0	8.0
	11.0	10.0	9.0	8.5	9.5	9.0	9.0	8.0
	10.0	10.0	9.0	6.5	9.5	10.0	8.0	9.0
	10.5	9.0	9.0	8.5	9.5	10.0	8.0	8.0
Average	10.5	9.5	9.0	7.5	9.5	9.5	8.5	8.3

TABLE XVI.–DATA ON ALUMINUM ALLOY NO. CS41A-T6 (0.25-IN. CLAD PLATE, PANEL).

ASTM Specification Requirements	As Received	Control	6-month Exposure			1-yr Exposure		
			State College	New York	Kure Beach	State College	New York	Kure Beach
YIELD STRENGTH, 0.2 PER CENT OFFSET, PSI								
57 000 psi, min	58 000	59 300	59 100	59 000	58 400	58 800	59 000	59 200
	58 000	59 200	59 700	58 900	58 300	59 500	58 800	58 600
	57 700	59 300	59 500	59 300	58 600	59 000	58 700	58 800
	58 000	59 500	59 400	59 100	58 200	59 100	59 600	59 100
Average	57 900	59 300	59 400	59 100	58 400	59 100	59 000	58 900
TENSILE STRENGTH, PSI								
64 000 psi, min	66 000	66 000	66 900	66 300	65 900	65 900	66 100	65 900
	67 000	65 900	67 100	66 500	66 100	66 300	66 200	66 000
	66 800	66 000	67 100	66 400	66 000	63 100	65 700	66 000
	66 800	66 300	67 000	68 300	66 000	65 800	65 700	66 000
Average	66 700	66 100	67 000	66 900	66 000	65 300	65 900	66 000
ELONGATION IN 2 IN., PER CENT								
8.0 per cent, min	10.5	10.0	9.0	9.0	10.5	10.0	10.0	11.0
	10.0	9.0	9.0	9.5	11.0	10.0	10.0	10.0
	10.5	9.0	9.0	9.5	10.0	10.0	10.0	10.0
	10.5	9.0	10.0	9.0	11.0	10.0	10.0	11.0
Average	10.4	9.3	9.3	9.3	10.6	10.0	10.0	10.5

TABLE XVII.—DATA ON ALUMINUM ALLOY NO. CG42A-T4 (0.25-IN. CLAD PLATE, PANEL).

ASTM Specification Requirements	As Received	Control	6-month Exposure			1-yr Exposure		
			State College	New York	Kure Beach	State College	New York	Kure Beach
YIELD STRENGTH, 0.2 PER CENT OFFSET, PSI								
40 000 psi, min	41 400	44 500	43 600	43 700	44 400	44 000	43 600	44 000
	41 800	44 200	43 700	43 600	44 400	43 900	43 200	44 800
	41 700	44 600	43 600	43 500	45 000	44 400	43 400	44 400
	42 500	44 600	43 600	43 500	45 800	44 400	44 200	44 600
Average	41 900	44 500	43 600	43 600	44 900	44 200	43 600	44 500
TENSILE STRENGTH, PSI								
62 000 psi, min	65 600	66 100	65 800	64 900	66 400	65 900	64 400	65 400
	65 400	66 000	65 000	65 100	66 600	66 000	64 500	66 000
	65 300	66 300	65 200	65 200	66 700	66 100	64 500	66 000
	65 000	65 900	65 000	65 100	67 300	65 800	64 600	66 100
Average	65 300	66 100	65 300	65 100	66 800	66 000	64 500	65 900
ELONGATION IN 2 IN., PER CENT								
11.0 per cent, min	18.5	19.0	21.0	19.0	19.0	19.0	15.0	19.0
	20.0	18.0	18.5	19.0	19.0	20.0	19.0	19.0
	19.5	18.0	19.5	19.0	19.0	19.0	16.0	19.0
	19.0	18.0	18.5	19.0	19.0	18.0	20.0	19.0
Average	19.3	18.3	19.4	19.0	19.0	19.0	17.5	19.0

TABLE XVIII.—DATA ON ALUMINUM ALLOY NO. ZG62A-T6 (0.25 IN. CLAD PLATE, PANEL).

ASTM Specification Requirements	As Received	Control	6-month Exposure			1-yr Exposure		
			State College	New York	Kure Beach	State College	New York	Kure Beach
YIELD STRENGTH, 0.2 PER CENT OFFSET, PSI								
62 000 psi, min	65 600	67 300	66 400	67 000	67 100	65 600	67 000	66 900
	66 000	67 400	66 900	67 000	66 900	66 400	66 200	65 800
	65 300	67 300	66 700	66 500	67 300	66 400	66 700	67 000
	63 100	67 300	67 000	67 000	66 800	66 400	66 700	67 200
Average	65 000	67 300	66 800	66 900	67 000	66 200	66 700	66 700
TENSILE STRENGTH, PSI								
72 000 psi, min	77 000	76 700	76 800	76 700	76 700	76 200	76 800	76 600
	77 000	74 800	76 800	76 500	77 100	76 500	76 600	76 600
	77 000	76 700	76 800	76 600	77 200	76 400	76 600	76 400
	76 600	76 600	76 800	76 600	77 000	76 500	76 400	76 600
Average	76 900	76 200	76 800	76 600	77 000	76 400	76 600	76 600
ELONGATION IN 2 IN., PER CENT								
8.0 per cent, min.	11.0	10.0	10.0	9.0	11.0	10.0	9.0	11.0
	10.5	9.0	9.0	9.0	11.0	9.0	9.0	11.0
	11.0	9.0	10.0	9.0	11.0	10.0	10.0	10.0
	10.5	9.0	10.0	9.0	11.0	11.0	10.0	9.0
Average	10.8	9.3	9.8	9.0	11.0	10.0	9.5	10.3

TABLE XIX.—DATA ON ALUMINUM ALLOY NO. GS11A-T6 (0.25 IN. EXTRUDED BAR, PANEL).

ASTM Specification[a] Requirements	As Received	Control	6-month Exposure			1-yr Exposure		
			State College	New York	Kure Beach	State College	New York	Kure Beach
YIELD STRENGTH, 0.2 PER CENT OFFSET, PSI								
35 000 psi, min	40 200	40 100	40 000	40 200	39 600	38 900	40 000	39 100
	40 100	40 200	40 300	39 400	40 000	39 300	40 000	39 700
	39 700	40 200	40 700	39 400	39 900	40 100	39 500	40 200
	40 400	40 800	40 600	39 900	38 800	40 400	39 700	40 200
Average	40 100	40 300	40 400	39 700	39 600	39 700	39 800	39 800
TENSILE STRENGTH, PSI								
38 000 psi, min	43 500	43 200	43 100	43 000	42 800	43 300	42 900	42 300
	43 300	43 400	43 800	42 100	43 000	43 900	43 200	42 800
	43 100	43 400	43 500	42 200	42 600	43 600	43 000	43 200
	43 400	43 800	43 200	42 600	42 500	43 400	42 600	43 100
Average	43 300	43 500	43 400	42 500	42 700	43 600	42 900	42 900
ELONGATION IN 2 IN., PER CENT								
10.0 per cent, min	17.0	15.0	16.0	14.5	17.0	16.0	15.0	15.0
	17.0	16.0	16.0	14.5	17.0	16.0	16.0	16.0
	16.0	15.0	16.0	14.5	17.0	15.0	15.0	15.0
	17.0	14.0	16.0	14.5	17.0	16.0	15.0	16.0
Average	16.8	15.0	16.0	14.5	17.0	15.8	15.3	15.5

[a] Tentative Specification for Aluminum and Aluminum-Alloy Extruded, Bars, Rods, and Shapes (B 221 – 53 T), 1953 Supplement to Book of ASTM Standards, Part 2, p. 169.

TABLE XX.—DATA ON ALUMINUM ALLOY NO. GS10A-T5 (0.25 EXTRUDED BAR, PANEL).

ASTM Specification Requirements	As Received	Control	6-month Exposure			1-yr Exposure		
			State College	New York	Kure Beach	State College	New York	Kure Beach
Yield Strength, 0.2 per cent Offset, psi								
16 000 psi	23 800	23 400	23 100	23 600	24 000	23 500	24 000	27 200
	23 800	23 800	23 500	24 000	24 100	23 000	23 700	26 600
	23 500	23 800	23 900	24 000	23 600	23 000	23 900	27 400
	23 400	23 800	23 600	24 200	24 000	23 600	23 900	27 200
Average	23 600	23 700	23 500	24 000	23 900	23 300	23 900	27 100
Tensile Strength, psi								
22 000 psi, min	28 500	28 300	28 300	28 400	28 200	28 400	28 500	31 300
	28 500	28 100	28 700	28 800	28 000	28 500	28 300	30 800
	28 500	29 600	28 800	28 700	27 800	28 100	28 400	31 200
	28 200	28 400	28 600	28 600	28 000	28 300	28 300	30 800
Average	28 400	28 600	28 600	28 600	28 000	28 300	28 400	31 000
Elongation in 2 in., Per Cent								
8.0 per cent, min	15.5	16.0	16.0	16.0	16.5	16.0	16.0	15.0
	16.0	16.0	16.0	16.0	16.5	17.0	16.0	16.0
	16.0	16.0	16.0	16.0	16.5	16.0	16.0	15.0
	16.0	16.0	16.0	16.0	16.5	16.0	16.0	16.0
Average	15.9	16.0	16.0	16.0	16.5	16.3	16.0	15.5

TABLE XXI.—DATA ON ALUMINUM ALLOY NO. CS41A-T4 (0.25 IN. EXTRUDED BAR, PANEL).

ASTM Specification Requirements	As Received	Control	6-month Exposure			1-yr Exposure		
			State College	New York	Kure Beach	State College	New York	Kure Beach
Yield Strength, 0.2 per cent Offset, psi								
35 000 psi, min	39 200	39 600	39 200	42 100	42 400	40 600	39 100	39 800
	41 600	41 700	41 300	39 300	39 700	41 800	41 500	41 200
	41 000	41 700	42 700	41 600	40 200	42 300	38 100	40 000
	38 200	39 200	40 000	39 600	41 700	40 000	42 300	41 200
Average	40 000	40 600	40 800	40 700	41 000	41 200	40 300	40 600
Tensile Strength, psi								
50 000 psi, min	56 400	56 500	57 700	59 400	58 000	57 800	57 000	56 600
	57 800	57 000	59 200	55 700	56 200	59 600	58 800	57 500
	58 300	58 000	59 600	58 900	56 100	59 700	56 600	56 600
	56 600	56 500	56 900	57 200	57 300	56 300	58 900	58 100
Average	57 300	57 000	58 400	57 800	56 900	58 400	57 800	57 200
Elongation in 2 in., Per Cent								
12.0 per cent, min	28.5	25.0	24.0	21.5	22.5	24.0	26.0	27.0
	23.5	23.0	19.5	24.5	25.0	23.0	24.0	24.0
	24.0	24.0	19.0	19.5	26.0	22.0	24.0	27.0
	27.0	26.0	23.5	26.0	22.5	24.0	22.0	25.0
Average	25.8	24.5	21.5	22.9	24.0	23.3	24.0	25.8

TABLE XXII.—DATA ON ALUMINUM ALLOY NO. CS41A-T6 (0.25 IN. EXTRUDED BAR, PANEL).

ASTM Specification Requirements	As Received	Control	6-month Exposure			1-yr Exposure		
			State College	New York	Kure Beach	State College	New York	Kure Beach
Yield Strength, 0.2 per cent Offset, psi								
53 000 psi, min	59 800	60 700	61 500	58 500	59 800	58 400	58 200	59 900
	61 200	60 600	61 300	61 100	60 000	58 400	61 400	61 500
	60 900	61 000	60 200	61 500	57 500	61 400	61 700	....
	58 900	59 800	60 100	60 400	61 300	61 500	57 900	61 400
Average	60 200	60 500	60 800	60 400	59 700	59 900	59 800	60 900
Tensile Strength, psi								
60 000 psi, min	64 600	65 100	65 100	64 200	64 300	62 900	63 700	64 900
	65 800	65 000	64 900	64 500	65 200	63 100	67 000	65 800
	65 800	64 400	63 500	64 600	62 500	66 300	65 800	64 600
	63 400	63 400	63 500	64 100	65 500	65 600	64 100	66 900
Average	64 900	64 500	64 300	64 400	64 400	64 500	65 200	65 600
Elongation in 2 in., Per Cent								
7.0 per cent, min	15.0	11.0	11.5	13.5	11.0	12.0	14.0	13.0
	10.5	11.0	12.0	10.0	11.5	14.0	12.0	13.0
	10.0	12.0	12.5	10.5	14.5	12.0	12.0	13.0
	12.0	14.0	11.5	12.0	11.5	12.0	14.0	12.0
Average	11.9	12.0	11.9	11.5	12.1	12.5	13.0	12.8

TABLE XXIII.—DATA ON ALUMINUM ALLOY NO. ZG62A-T6 (0.25 IN. EXTRUDED BAR, PANEL).

ASTM Specification Requirements	As Received	Control	6-month Exposure			1-yr Exposure		
			State College	New York	Kure Beach	State College	New York	Kure Beach
Yield Strength, 0.2 per cent Offset, psi								
72 000 psi, min	82 700	78 500	79 000	83 500	77 900	79 200	83 800	79 900
	79 500	81 000	84 500	79 400	78 400	79 300	77 600	83 100
	86 000	79 300	85 300	80 500	81 200	83 300	78 600	85 700
	85 000	87 800	78 700	84 800	82 800	85 400	83 800	80 100
Average	83 300	81 700	81 900	82 100	80 100	81 800	81 000	82 200
Tensile Strength, psi								
80 000 psi, min	91 000	87 300	88 000	90 600	86 400	87 900	91 200	88 500
	88 000	93 200	92 100	87 500	87 100	88 000	85 900	91 200
	89 200	87 300	92 100	88 000	89 100	91 700	86 900	92 600
	92 600	94 400	86 700	90 700	89 400	92 700	90 900	87 500
Average	90 200	90 600	89 700	89 200	88 000	90 100	88 700	90 000
Elongation in 2 in., Per Cent								
7.0 per cent, min.	12.5	10.0	10.0	9.0	10.5	11.0	11.0	9.0
	11.0	9.0	11.0	9.0	10.0	11.0	9.0	11.0
	12.0	9.0	11.0	9.0	9.0	12.0	9.0	10.0
	13.0	10.0	10.0	9.0	10.0	10.0	10.0	11.0
Average	12.1	9.5	10.5	9.0	9.9	11.0	9.8	10.3

TABLE XXIV.—DATA ON ALUMINUM ALLOYS NOS. GS11A-T6, CS41A-T6, CG42A-T4, AND ZG62A-T6 (0.064-IN. SHEET, SPOT WELD[a]).

	Breaking Load, lb							
	As Received	Control	6-month Exposure			1-yr Exposure		
			State College	New York	Kure Beach	State College	New York	Kure Beach
				Alloy No. GS11A-T6				
	1340	1640	1500	1850	1440	1745	1410	1555
	1430	1560	1410	1500	1660	1310	1610	1480
	1460	1510	1630	1600	1470	1475	1485	1410
	1520	1500	1390	1480	1420	1505	1505	1495
Average	1438	1553	1483	1608	1498	1509	1503	1485
				Alloy No. CS41A-T6—Clad				
	1790	1830	1990	1840	2320	1920	1915	1760
	1900	1845	1780	2030	1650	2085	1825	2055
	1710	1940	2020	2060	2160	2050	1875	1555
	1750	1830	1650	2070	2200	2195	1780	2105
Average	1788	1861	1860	2000	2083	2063	1849	1869
				Alloy No. CG42A-T4—Clad				
	2650	1880	2150	2180	1820	1770	2020	2045
	2480	2170	1980	1760	2110	1860	2025	1985
	2540	2090	2150	2000	2110	2000	1890	1785
	2610	1860	2190	1860	2020	2185	2095	1940
Average	2570	2000	2118	1950	2015	1954	2008	1939
				Alloy No. ZG62A-T6—Clad				
	2290	2256	2490	2210	2030	2200	1692	1708
	2250	2088	2270	1990	2000	2224	2224	1684
	2170	1950	2630	2220	1940	2034	1786	1656
	2450	2198	2630	2250	1880	2490	1710	1510
Average	2290	2123	2505	2168	1963	2237	1853	1640

[a] Values are shear results for 2 spot welds on a single lap joint.

TABLE XXV.—DATA ON ALUMINUM ALLOYS NOS. GS11A-T6 AND GS10A-T5.

	TENSILE STRENGTH, PSI							
	As Received[a]	Control	6-month Exposure			1-yr Exposure		
			State College	New York	Kure Beach	State College	New York	Kure Beach
ALLOY NO. GS11A-T6 (0.25-IN. PLATE, GAS WELD)								
	22 100[b]	24 300[b]	19 600	25 000[b]	24 800[b]	22 700[b]	23 000[b]	18 400
	22 000	23 200	22 000[b]	24 400	22 400	22 900[b]	22 600[b]	25 100
	22 200	23 600[b]	21 800[b]	24 800	22 100	23 200[b]	23 000[b]	16 800
	22 600[b]	23 000[b]	21 800[b]	27 600[b]	24 100	23 300[b]	22 900[b]	24 500
Average	22 200	23 500	21 300	25 400	23 400	23 000	22 900	21 200
ALLOY NO. GS11A-T6 (0 25-IN. PLATE, ARC WELD)								
	20 200	24 500	20 800	23 800	26 000[b]	23 000[b]	25 600	23 200
	21 000	25 900[b]	22 500	26 200[b]	25 600[b]	22 100	24 600	24 800
	20 400	17 800	20 000	24 400	26 000[b]	20 500[b]	25 900	18 800
	25 800[b]	22 000	20 800	24 100	26 400[b]	23 000	22 700	21 500
Average	21 900	22 600	21 000	24 600	26 000	22 200	24 700	22 100
ALLOY NO. GS10A-T5 (0.25-IN. EXTRUDED BAR, ARC WELD)								
	19 100[b]	20 700[b]	20 400[b]	21 600[b]	21 300[b]	20 600[b]	21 400[b]	21 900
	19 800[b]	21 000[b]	20 800[b]	21 200[b]	23 200[b]	20 700[b]	21 700[b]	21 800
	19 300[b]	....	20 800[b]	20 600[b]	21 700[b]	20 800[b]	21 600[b]	21 900
	18 800[b]	20 400[b]	20 300[b]	22 400[b]	21 400[b]	20 400[b]	21 300[b]	21 500
Average	19 300	20 700	20 600	21 500	21 900	20 600	21 500	21 800

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[a] PSI on "As Received" samples determined by using standard 0.5-in. width and 0.25-in. thicknesses, since only load-lb values were supplied.

[b] Samples broke in Base Material. All other samples broke in Weld.

TABLE XXVI.—DATA ON ALUMINUM ALLOYS NOS. GS11A-T6, CG42A-T3, AND ZG62A-T6 (0.064-IN. SHEET, RIVET[a, b])

	TENSILE STRENGTH, PSI							
	As Received[c]	Control	6-month Exposure			1-yr Exposure		
			State College	New York	Kure Beach	State College	New York	Kure Beach
				ALLOY No. GS11A-T6				
		46 200	44 700	44 100	44 500	46 700	46 400	44 500
		46 600	46 300	46 000	45 700	47 800	46 400	45 800
		45 200	46 100	45 900	43 800	47 800	46 600	45 100
		46 600	44 700	46 500	45 100	46 400	46 000	44 500
		46 400	45 700	46 000	43 800	47 100	46 000	45 200
		46 400	46 000	45 500	44 700	46 800	46 400	44 900
Average		46 200	45 600	45 700	44 600	47 100	46 300	45 000
				ALLOY No. CG42A-T3				
		60 100	61 600	63 600	60 100	63 200	63 700	61 400
		62 700	61 900	61 600	61 800	63 300	63 700	63 500
		63 900	60 800	....	62 500	61 700	60 300	63 600
		64 000	62 100	63 700	63 300	61 300	63 400	62 100
		58 400	61 900	63 600	63 200	62 700	63 500	63 500
		....	60 100	61 100	63 100	....	63 500	63 100
Average		61 800	61 400	62 700	62 300	62 400	63 000	62 900
				ALLOY No. ZG62A-T6				
		78 800	75 100	74 200	76 800	....	78 400	79 400
		78 800	74 200	74 400	75 700	75 900	77 600	77 600
		77 600	73 900	75 900	76 600	78 300	78 700	79 000
		....	75 700	74 500	76 800	78 900	78 300	76 900
		78 900	74 200	75 600	75 800	79 500	77 800	77 600
		75 300	75 500	75 500	76 500	80 000	77 800	80 000
Average		77 900	74 800	75 000	76 400	78 500	78 100	78 400

[a] Net Area = Width − diameter of rivet hole × Thickness.

[b] All specimens failed in sheet.

[c] No "As Received" results since only breaking load values were supplied.

TABLE XXVII.—DATA ON ALUMINUM ALLOYS NOS. CS41A-T6, CG42A-T4, AND ZG62A-T6 (0.064-IN. CLAD SHEET, RIVET[a]).

	Tensile Strength, psi							
	As Received[b]	Control	6-month Exposure			1-yr Exposure		
			State College	New York	Kure Beach	State College	New York	Kure Beach
Alloy No. CS41A-T6								
		64 900	63 400	66 100	64 700	61 300	64 700	65 300
		67 400	66 100	65 700	66 800	67 700	65 100	66 500
		65 500	66 000	67 800	67 100	67 000	65 100	60 200
		64 500	66 100	65 800	66 400	64 800	66 200	66 200
		....	65 700	65 700	67 100	65 000	64 300	67 000
		63 400	66 100	65 800	65 100	67 600	63 000	....
Average		65 100	65 600	66 200	66 200	65 600	64 700	65 000
Alloy No. CG42A-T4								
		59 200	61 900	64 100	61 300	61 000	63 100	62 900
		61 100	61 600	61 600	61 500	62 800	63 500	59 600
		61 200	63 400	64 300	61 700	61 700	61 100	58 400
		62 000	60 800	62 700	62 400	58 300	61 800	68 100
		60 200	62 900	60 600	60 800	60 600	63 400	52 500
		....	63 500	65 000	60 300	58 600	61 400	55 500
Average		60 700	62 400	63 100	61 300	60 500	62 400	59 500
Alloy No. ZG62A-T6								
		77 900	73 100	74 700	76 100	74 400	76 000	77 900
		75 800	74 600	74 000	75 400	74 200	76 000	79 700
		76 000	73 200	72 900	75 700	74 900	76 100	79 600
		76 500	73 600	74 500	75 800	75 000	72 000	79 900
		76 200	74 000	74 700	75 900	75 700	75 900	79 200
		69 400	74 100	74 500	76 400	73 200	74 600	75 800
Average		75 300	73 800	74 200	75 900	74 600	75 100	78 700

[a] All specimens failed in sheet.

[b] No "As Received" results since only breaking load values were supplied.

TABLE XXVIII.—DATA ON MAGNESIUM ALLOYS NOS. M1A-O AND AZ31A-H24.

	ASTM Specification[b]	As Received	Control	6-Month Exposure			1-yr Exposure		
				State College	New York	Kure Beach	State College	New York	Kure Beach
ALLOY No. M1A-O (0.064-IN. SHEET)									
Yield strength, psi[a]	....	15 300	16 600	17 300	15 700	15 200	16 500	16 500	17 000
Tensile strength, psi	38 000 max	31 400	31 900	30 900	31 200	31 600	32 100	29 800	30 300
Elongation in 2 in., per cent	12.0 min	20.5	18.5	19.0	18.0	12.9	11.9[c]	16.3	11.3[c]
ALLOY No. AZ31A-H24 (0.064-IN. SHEET)									
Yield strength psi[a]	29 000 min	31 300	30 700	28 100[c]	28 800[c]	31 100	29 500	29 000	30 600
Tensile strength, psi	39 000	41 900	41 900	39 800	40 600	43 300	40 300	40 300	42 400
Elongation in 2 in., per cent	4.0 min	18.0	16.0	14.5	13.0	9.5	9.9	13.0	10.3
ALLOY No. AZ31A-H24 (0.25-IN. PLATE)									
Yield strength, psi[a]	29 000 min	32 900	32 400	32 000	30 700	32 400	32 000	32 200	32 700
Tensile strength, psi	39 000 min	41 900	42 100	41 300	39 800	41 900	41 900	41 500	42 300
Elongation in 2 in., per cent	4.0 min	21.0	17.4	17.5	15.5	16.1	11.6	13.6	13.5

[a] Yield Strength, 0.2 per cent offset. Values are averages of 4 tests.

[b] Tentative Specification for Magnesium-Base Alloy Sheet (B 90 – 51 T), 1952 Book of ASTM Standards, Part 2, p. 533.

[c] Low.

TABLE XXIX.—DATA ON MAGNESIUM ALLOYS NOS. M1A-F, AZ31B-F, AZ80A-T51, AND ZK60A-F (0.25-IN. EXTRUDED BAR).

	ASTM Specification[b]	As Received	Control	6-Month Exposure			1-yr Exposure		
				State College	New York	Kure Beach	State College	New York	Kure Beach
ALLOY NO. M1A-F									
Yield strength psi[a]	....	21 700	21 800	23 000	24 500	22 300	23 300	23 500	22 500
Tensile strength, psi	32 000 min	32 900	32 600	33 300	34 000	32 500	33 700	33 100	32 900
Elongation in 2 in., per cent	3.0 min	16.0	14.0	11.0	9.0	10.8	8.3	8.0	6.9
ALLOY NO. AZ31B-F									
Yield strength psi[a]	20 000 min	24 700	25 000	24 600	24 900	25 500	24 700	24 700	25 700
Tensile strength, psi	32 000 min	38 700	38 800	38 000	38 100	37 600	38 400	37 800	37 700
Elongation in 2 in., per cent	7.0 min	17.0	16.9	17.5	15.0	13.8	14.9	16.0	16.0
ALLOY NO. AZ80A-T51									
Yield strength, psi[a]	32 000 min	38 700	39 000	38 700	38 600	38 900	38 100	37 700	39 200
Tensile strength, psi	47 000 min	54 100	53 500	52 900	52 500	53 700	53 800	51 700	53 600
Elongation in 2 in., per cent	3.0 min	13.0	12.4	7.5	6.0	11.4	8.4	6.8	9.1
ALLOY NO. ZK60A-F									
Yield strength, psi[a]	31 000 min	34 800	36 000	36 000	35 700	35 800	34 800	35 700	36 300
Tensile strength, psi	43 000 min	46 500	47 100	47 000	46 900	46 800	46 000	45 900	46 600
Elongation in 2 in., per cent	5.0 min	12.0	9.9	12.5	10.0	9.5	11.4	13.5	10.8

[a] Yield Strength, 0.2 per cent Offset. Values are averages of 4 tests.

[b] Tentative Specification for Magnesium-Base Alloy Bars, Rods, and Shapes (B 107 – 53 T), 1953 Supplement to Book of ASTM Standards, Part 2, p. 134.

TABLE XXX.—DATA ON MAGNESIUM ALLOYS NOS. M1A-O, AZ31A-H24, AZ31B-F, AND ZK60A-F.[a]

As Received	Control	Breaking Load, lb					
		6-Month Exposure			1-yr Exposure		
		State College	New York	Kure Beach	State College	New York	Kure Beach
Alloy No. M1A-O (0.064 Sheet, Spot Weld)[b]							
790	552	495	579	560	504	473	491
Alloy No. AZ31A-H24 (0.064-in. Sheet, Spot Weld)[b]							
575	573	575	660	623	685	661	662
Alloy, No. M1A-O (0.064-in. Sheet, Rivet)							
1380	1288	1330	1420	1290	1310	1340	1308
Alloy No. AZ31A-H24 (0.064-in. Sheet, Rivet)							
1900	1980	1950	1950	2035	2080	1870	1738
Alloy No. AZ31B-F (0.25-in. Extruded Bar, Rivet)							
5350	4825	5530	5380	4631	5377	4863	4635
Alloy No. ZK60A-F (0.25-in. Extruded Bar, Rivet)							
6170	5716	6580	6300	5800	6527	5650	5323

[a] Values are averages of 3 tests.

[b] Spot Weld: Values are shear results for 2 spot welds on a singe lap joint.

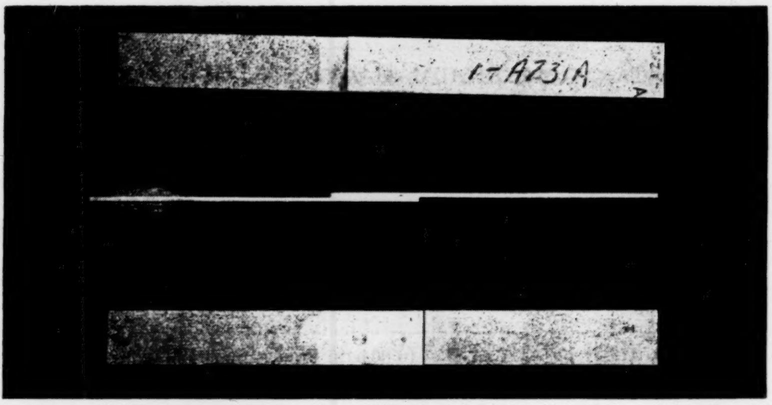

FIG. 1.—Type of Aluminum or Magnesium Alloy Specimen Used in Determining Breaking Load of Lap Joint of Spot Welded Sheet, 0.064 in. Thick.

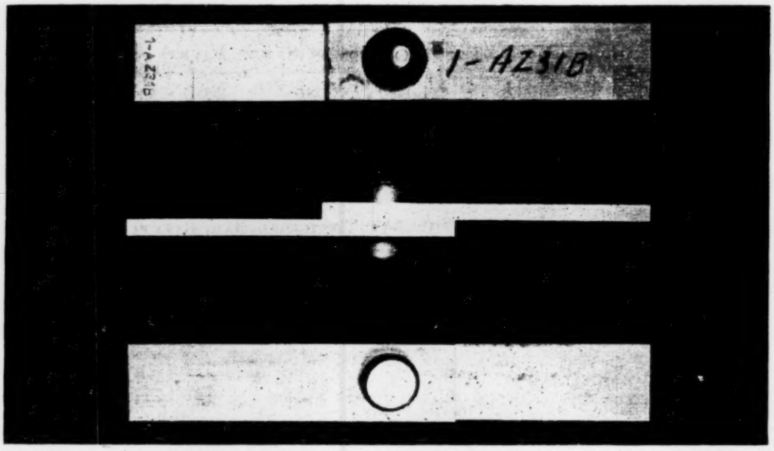

FIG. 2.—Type of Riveted Specimen Cut From Magnesium Alloy Extruded Specimens, 0.025 in. Thick.

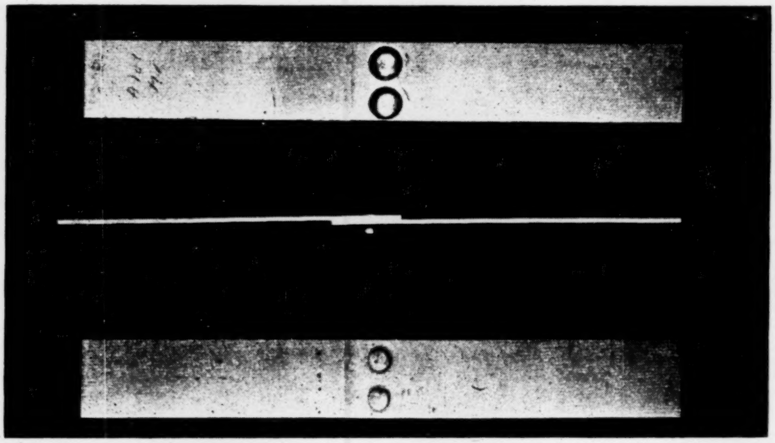

FIG. 3.—Type of Riveted Specimen Cut From Magnesium Alloy Sheet, 0.064 in. Thick.

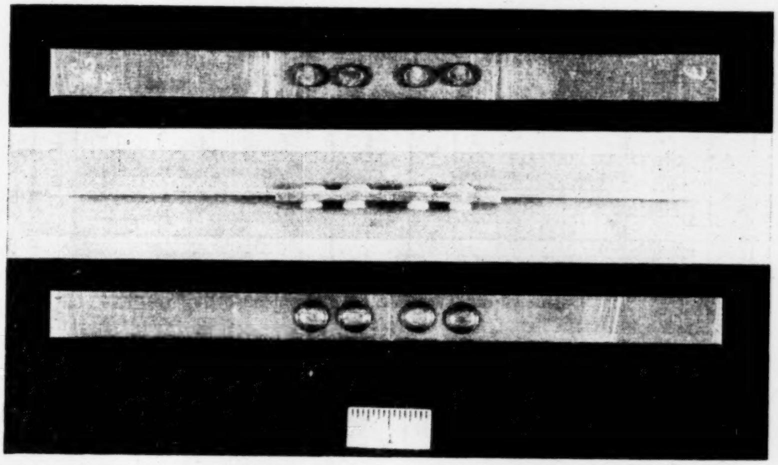

FIG. 4.—Type of Riveted Specimen Cut From Aluminum Alloy Sheet, 0.064 in. Thick.

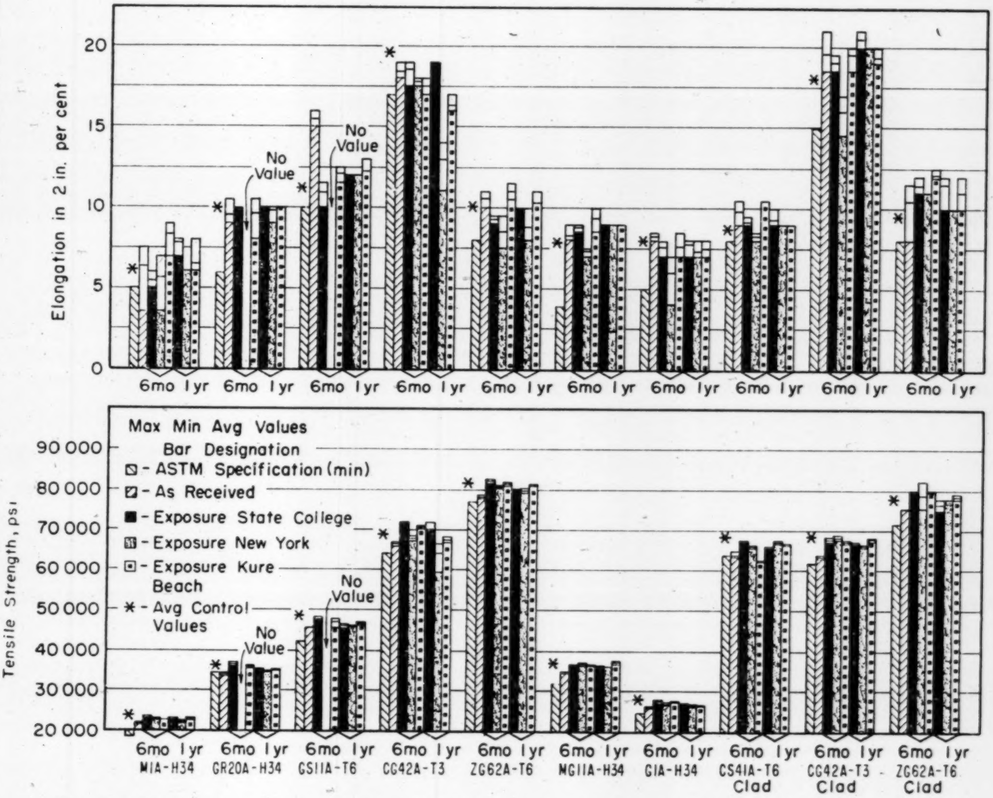

FIG. 5.—Summary of Data on Atmospheric Exposure of Light Metals and Alloys—Aluminum Panels (0.064 in. Thick).

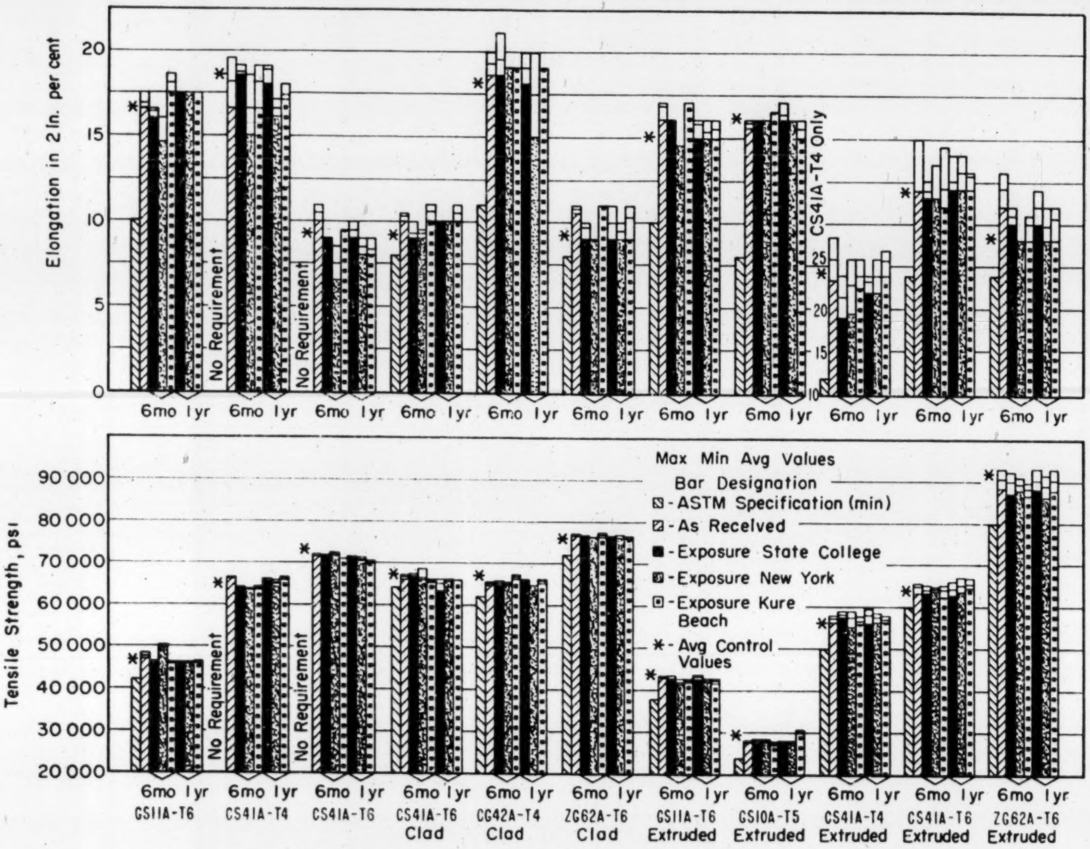

FIG. 6.—Summary of Data on Atmospheric Exposure of Light Metals and Alloys—Aluminum Panels (0.25 in. Thick).

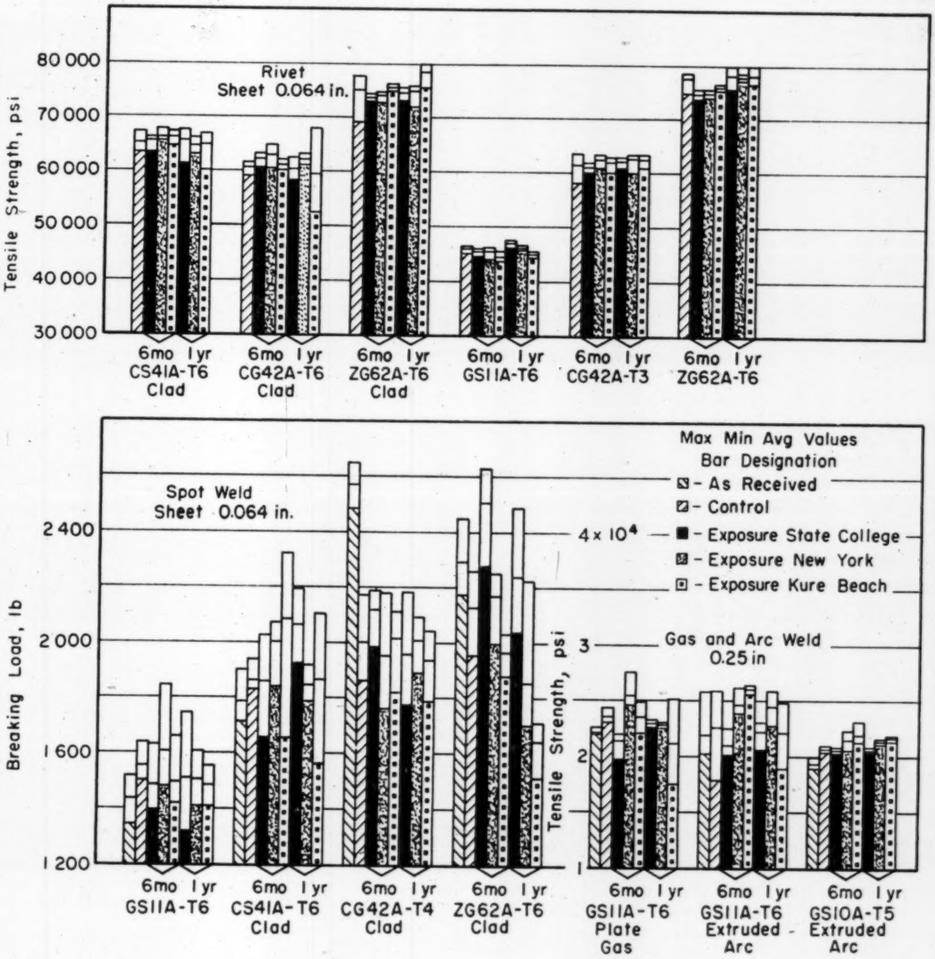

FIG. 7.—Summary of Data on Atmospheric Exposure of Light Metals and Alloys—Aluminum Alloys.

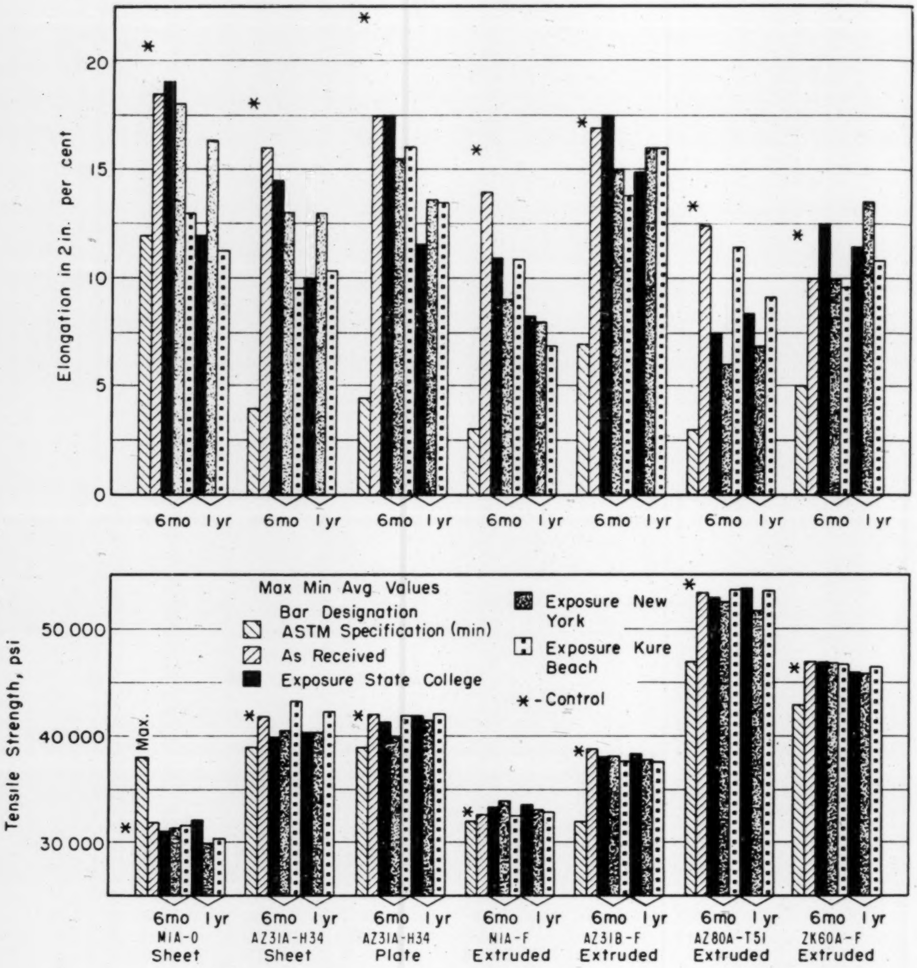

FIG. 8.—Summary of Data on Atmospheric Exposure of Light Metals and Alloys—Magnesium Alloys.

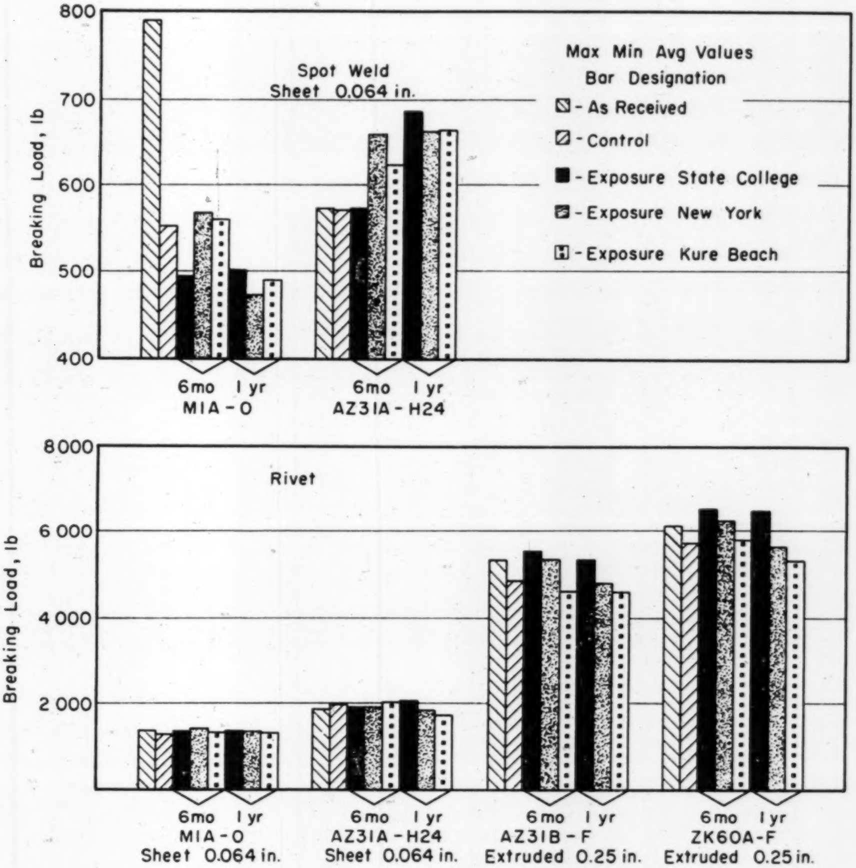

FIG. 9.—Summary of Data on Atmospheric Exposure of Light Metals and Alloys—Magnesium Alloys.

REPORT OF COMMITTEE B-8
ON
ELECTRODEPOSITED METALLIC COATINGS*

Committee B-8 held two meetings during the year: on September 24, 1954, at ASTM Headquarters in Philadelphia, Pa., and in Cincinnati, Ohio, on February 4, 1955.

The membership of the committee now totals 129, of whom 52 are classified as producer, 18 as consumer, 59 as general interest, and 14 as consulting members.

REVISION OF TENTATIVES

The committee recommends that the following tentative specifications be revised as indicated and continued as tentative:

Tentative Specifications for Electrodeposited Coatings of Nickel and Chromium on Steel (A 166 - 54 T):[1]

Section 5.—Change to read as follows:

5. In general, significant surfaces (Note) are those surfaces that are visible and subject to wear or corrosion or both, or surfaces on which the coating is otherwise functionally necessary. The designation of significant surfaces shall be agreed upon by the manufacturer and purchaser and may be indicated on the drawings. Surfaces on which a controlled deposit ordinarily cannot be obtained, such as holes, recesses, bases of angles, and similar areas, are normally exempt from the requirements for significant surfaces, unless they are specifically designated as such. When such areas are designated as significant surfaces, and the thickness requirements must be met, the manufacturer and purchaser shall recognize the necessity for either thicker deposits on the more accessible surfaces or for special racking. Special racks may involve the use of conforming, auxiliary, interior, or bi-polar electrodes.

NOTE.—It is suggested that significant surfaces generally may be defined as those parts of the visible surface that can be touched with a $\frac{3}{4}$-in. diameter sphere or with a sphere of a diameter agreed upon by the manufacturer and the purchaser.

Tentative Specifications for Electrodeposited Coatings of Lead on Steel (B 200 - 54 T):[1]

Section 5.—Change to read as shown for Section 5 of Tentative Specification A 166 above.

Tentative Specifications for Chromate Finishes on Electrodeposited Zinc, Hot-Dipped Galvanized, and Zinc Die-Cast Surfaces (B 201 - 54 T):[1]

Section 4.—Change to read as follows:

4. In general, significant surfaces are those surfaces that are visible and subject to wear or corrosion, or both, or surfaces on which the coating is otherwise functionally necessary. The designation of significant surfaces shall be agreed upon by the manufacturer and the purchaser and may be indicated on the drawings.

Section 5.—Change the last sentence to read: "All of the samples shall be visually examined . . . ."

REVISION OF STANDARDS, IMMEDIATE ADOPTION

The committee recommends for immediate adoption revisions in the following five standards, and accordingly asks for the necessary nine-tenths affirmative vote at the Annual Meeting in order that the revisions may be referred to letter ballot of the Society:

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* Presented at the Fifty-eighth Annual Meeting of the Society, June 26–July 1, 1955.

[1] 1954 Supplement to Book of ASTM Standards, Part 2.

Standard Specifications for Electrodeposited Coatings of Zinc on Steel (A 164 – 53):[2]

Section 4.—Change to read as shown for Section 5 of Tentative Specification A 166 above.

Section 6.—Change the last sentence to read "All of the samples shall be visually examined. . ."

Section 7.—Add the following Note:

NOTE.—Wherever possible, thicknesses should be measured by magnetic methods on the maximum number of samples practicable since such measurements are non-destructive and inexpensive.

Standard Specifications for Electrodeposited Coatings of Cadmium on Steel (A 165 – 53):[2]

Section 4.—Change to read as shown for Section 5 of Tentative Specification A 166 above.

Section 6.—Change the last sentence to read "All of the samples shall be visually examined. . ."

Section 7.—Add the following Note:

NOTE.—Wherever possible, thicknesses should be measured by magnetic methods on the maximum number of samples practicable since such measurements are non-destructive and inexpensive.

Standard Specifications for Electrodeposited Coatings of Nickel and Chromium on Copper and Copper-Base Alloys (B 141 – 45):[2]

Section 3.—Change the first sentence to read as follows: "Coatings on the finished articles shall conform to the following requirements as to thickness on significant surfaces:"

Section 4.—Change to read as shown for Section 5 of Tentative Specification A 166 above.

Section 5.—Change the last sentence to read: "All of the samples shall be visually examined . . ."

Section 6.—Change to read as follows:

6. The number of test specimens subjected to each test shall be agreed upon by the manufacturer and the purchaser. The thickness of chromium shall be determined in accordance with Section 7(*a*) and the thickness of nickel in accordance with Section 7(*b*) or (*c*).

NOTE.—Wherever possible, thicknesses should be measured by magnetic methods on the maximum number of samples practicable since such measurements are non-destructive and inexpensive.

Standard Specifications for Electrodeposited Coatings of Nickel and Chromium on Zinc and Zinc-Base Alloys (B 142 – 54):[1]

Section 5.—Change to read as shown for Section 5 of Tentative Specification A 166 above.

Recommended Practice for Chromium Plating on Steel for Engineering Use (B 177 – 49):[2]

Section 7(b).—Add the following note:

NOTE: **Caution.**—Plated parts subject to alternating stresses, such as rotating shafts, or designed on the basis of fatigue characteristics and plated on areas subject to those stresses should not be baked, because baking generally tends to reduce the fatigue strength. High-strength steels (Rockwell C-40 and above) that are to be highly loaded in service should be baked as agreed upon between the purchaser and the seller. Special baking, plating, or other treatments may be required as determined by testing specific parts.

REAFFIRMATION OF STANDARD

The committee recommends the reapproval of the Recommended Practice for Preparation of Low-Carbon Steel for Electroplating (**B 183 – 49**).

TENTATIVE CONTINUED WITHOUT REVISION

Because of insufficient experience with its use, the committee recommends that the Recommended Practice for the Preparation of Copper and Copper-Base Alloys for Electroplating (**B 281 – 53 T**) be continued as tentative without revision.

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[2] 1952 Book of ASTM Standards, Part 2.

The recommendations in this report have been submitted to letter ballot of the committee, the results of which will be reported at the Annual Meeting.[3]

ACTIVITIES OF SUBCOMMITTEES

Subcommittee I on Papers, Specifications, and Definitions (F. Ogburn, chairman).—The symposium committee, now under the chairmanship of W. L. Pinner, has completed its plans for a Symposium on Properties, Tests, and Performance of Electrodeposited Metallic Coatings at the ASTM Committee Week in Buffalo in February, 1956. The Symposium will be repeated at the ASTM Pacific Area National Meeting in Los Angeles in September, 1956.

The task group appointed to investigate the need and desirability of writing specifications for materials used in electroplating recommended no action at present.

A section has made a detailed study of the specifications prepared by Committee B-8 with respect to uniformity and clarity, resulting in many of the changes recommended previously in this report.

Subcommittee II on Performance Tests (W. L. Pinner, chairman).—Inspections and ratings of steel panels plated with copper-nickel-chromium and steel panels coated with lead have been continued. These are covered in a progress report of Subcommittee II which is appended hereto.[4]

Plans for future exposure tests of copper-nickel-chromium and nickel-chromium on steel are being considered actively. Steel panels coated with copper-nickel-chromium and nickel-chromium will be exposed in the immediate future at New York, Kure Beach, State College, and Detroit for the purpose of obtaining typical corrosion patterns and demonstrating rating numbers.

Inspection and rating of exposed steel panels coated with zinc and zinc plus conversion coatings are being continued.

A new Section E has been formed under the chairmanship of F. Lowenheim to investigate performance of electrodeposited tin and tin alloy coatings.

Subcommittee III on Conformance Tests (R. F. Ledford, chairman).—Two new subgroups under Section C on Hardness have been appointed, one under the chairmanship of R. E. Harr to study indentation hardness tests as applied to electrodeposits, and the other under the chairmanship of M. B. Diggin to study methods of measuring ductility of electrodeposits.

A new Section F under the chairmanship of L. M. Morse will investigate methods of measuring stress in electrodeposits.

A task group under the chairmanship of M. Frager has been appointed to consider the effect of temperature on the service life of electrodeposited and hot-dipped zinc coatings with special emphasis on the effect on ductility of various basis metals.

Subcommittee IV on Electroplating Practice (M. Frager, chairman).—All existing sections are proceeding with their assignments. Recommendations affecting existing recommended practices appear earlier in this report.

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[3] The letter ballot vote on these recommendations was favorable; the results of the vote are on record at ASTM Headquarters.

[4] See p. 316.

Subcommittee V on Supplementary Treatments for Electrodeposited Metallic Coatings (M. Darrin, chairman).—Sections in Subcommittee V have been reorganized to avoid overlapping.

The cadmium plated panels prepared by Section E will be exposed in the immediate future at Kure Beach, New York, and Rock Island Arsenal.

The recommendations made jointly with Subcommittee I regarding revision of Specifications B 201 - 54 T appear earlier in this report.

This report has been submitted to letter ballot of the committee, which consists of 129 voting members; 99 members returned their ballots, of whom 82 have voted affirmatively and 0 negatively.

Respectfully submitted on behalf of the committee,

C. H. SAMPLE,
Chairman.

R. B. SALTONSTALL,
Secretary.

REPORT OF SUBCOMMITTEE II ON PERFORMANCE TESTS

The following report is divided into two parts. One part summarizes the results of atmospheric exposure of copper-nickel-chromium deposits on high-carbon steel. The other part of the report gives the results of the atmospheric exposure of electroplated lead coatings on steel.

ATMOSPHERIC EXPOSURE OF COPPER-NICKEL-CHROMIUM DEPOSITS ON HIGH-CARBON STEEL

This report is essentially a continuation of the 1953 report of Subcommittee II.[1] It contains exposure data from the copper-nickel-chromium plated panels of Program No. 1, which are still undergoing weathering tests after 7.2 yr at State College, Pa. It contains also the final exposure data on the Program No. 2 panels which had been on exposure at Kure Beach, N. C., and New York, N. Y., for 3.4 yr. Additionally, it contains the first exposure data on the Program No. 3 panels, after being tested for 1.1 yr at Kure Beach, New York City, and Detroit, Mich.

For the purpose of evaluating the exposure test data on the Program No. 3 panels, it is desirable to review the specific objectives of this latest program. The conclusions reached as a result of Program No. 1 included the statement that, in combination copper-nickel-chromium plated panels, the thickness of the nickel plate was the principal determining factor in the atmospheric weathering characteristics of such coatings. The report further stated that the copper undercoatings added little to the protective value of composite copper-nickel-chromium coatings and what little they did add was important only in the early stages of deterioration or in the mildest corrosive atmospheres. These conclusions were questioned by a few members on the basis that 0.0001 in. cyanide copper strike was insufficient to prevent possible deleterious action during the subsequent deposition of additional copper thickness from the acid copper bath employed. Test Program No. 2 was undertaken to ascertain the validity of this criticism.

Comparison of ratings between the panels of Program No. 1 and Program No. 2 is incongruous. It was recommended that additional test panels be prepared for performance testing to check further the validity of the original criticism of Program No. 1, with special emphasis on control and application of the coatings. This recommendation led to Program No. 3 which among other factors, including procedures for rating exposure test specimens, was designed primarily to compare the effect of the thickness of the cyanide copper flash underlying a substantial thickness of acid copper on the durability of combination copper-nickel-chromium coatings. These particular comparisons are represented in lots Nos. 2, 3, 4, and 5. Lots Nos. 6 and 7 were included to furnish reference points on a combination copper-nickel coating and a nickel coating over copper flash in which buffed Watt's nickel, the principal type of coating employed in Program No. 1, was substituted for bright nickel. Lot No. 1, consisting of all bright nickel plate, was included in the program to furnish a comparison between such a deposit and those made up of a combination of relatively substantial thicknesses of copper under bright nickel, as a base for decorative chromium.

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[1] *Proceedings*, Am. Soc. Testing Mats., Vol. 53, p. 256 (1953).

The Program No. 3 panels were plated in the development laboratory of United Chromium, Inc., in Detroit, Mich. The procedure for preparing these panels follows.

Preparation of Panels:

Test panels were prepared for performance testing to evaluate copper-nickel-chromium deposits with the thicknesses shown in Table I. Twenty-four panels were prepared for each lot. The lot number was stamped in the lower left-hand corner of the face, and the panel number in the lower right-hand corner.

The steel for all the test panels was from a single heat and was supplied by Oldsmobile Division, General Motors Corp. This was SAE 950 bumper stock steel furnished in strips 4 in. wide by 8 ft long, mill finish.

The steel was automatically flat polished in the long strips at the Murray-Way Co. As many as 20 to 30 passes on the polisher were used in order to remove all pits or scratches visible to the naked eye. After polishing, the surface roughness was 5 microinches rms as determined with the Physics Research Profilometer. The polished surface was coated with Unichrome Strippable Synthetic A-139 to protect the finish during shearing and handling before plating. The strips were sheared by Houdaille Hershey Corp. to 6-in. lengths to make the 4 by 6-in. test panels. After shearing to size, holes were drilled for racking. (See Appendix, part A, for detail.)

Plating Procedure:

Proprietary cleaners, anodic for steel and cathodic for copper, were used at the concentration and temperature recommended by the manufacturers (Appendix, parts B and C). The cyanide strike, nickel strike, Watt's nickel, and chromium plating solutions were all conventional baths, whereas the thiourea type acid copper and the bright nickel were proprietary processes (see Appendix). The following cycle was used on lots Nos. 2, 3, 4, 5, and 6. On lot No. 1, steps 6 through 16 were omitted. On lot No. 7, steps 10 through 18 were omitted. The nickel strike was used on lots Nos. 1 through 6 to insure adhesion of the subsequent bright nickel coatings to steel (lot No. 1) and buffed copper (lots Nos. 2, 3, 4, 5, and 6).

TABLE I.—TEST PANELS FOR PERFORMANCE TEST PROGRAM NO. 3.

Lot	Coatings, mils			
	Cyanide Copper	Thiourea Acid Copper	Bright Nickel	Chromium
No. 1	...	...	1.5	0.01
No. 2	0.2	0.8	0.5	0.01
No. 3	0.05	0.95	0.5	0.01
No. 4	0.05	0.45	1.0	0.01
No. 5	0.2	0.3	1.0	0.01
			Watt's Nickel	
No. 6	0.05	0.45	1.0	0.01
No. 7	0.1	...	1.4	0.01

Note.—The thicknesses of deposit for lots Nos. 2 and 3 are as shown above, which is the reverse of the outline given in the 1951 report of Subcommittee II.

Step	Procedure
No. 1	Remove strippable synthetic and rack
No. 2	Clean, anodic steel cleaner
No. 3	Water rinse
No. 4	Acid dip, 2 per cent H_2SO_4
No. 5	Water rinse
No. 6	Cyanide copper strike
No. 7	Water rinse
No. 8	Acid dip, 2 per cent H_2SO_4
No. 9	Water rinse
No. 10	Acid copper plate
No. 11	Water rinse
No. 12	Buff copper
No. 13	Clean, cathodic copper cleaner
No. 14	Water rinse
No. 15	Acid dip, 2 per cent H_2SO_4
No. 16	Water rinse
No. 17	Nickel strike
No. 18	Water rinse
No. 19	Nickel plate
No. 20	Water rinse
No. 21	Chromium plate

In those cases where Watt's nickel was used, the following was the procedure after step No. 19:

Step	Procedure
No. 19*a*	Buff nickel
No. 19*b*	Clean, cathodic copper cleaner
No. 19*c*	Water rinse
No. 19*d*	Acid dip, 2 per cent H_2SO_4
No. 19*e*	Water rinse
No. 19*f*	Chromium plate

Standardization and Racking:

Realizing that a test of this sort is of value only if the panels are the same, a great deal of care and time was used to standardize procedures, racking, and positioning in the tank. After standard time and current densities were established, each panel was tested with a magnegage for thicknesses of the various deposits. The magnegage was standardized by comparison with thickness determinations using the microscopic method on cross-sections of steel with acid copper, Watt's nickel, and bright nickel deposits plated in the baths used for plating the test panels. The test panels were found to be free of residual magnetism, and a demagnetizing treatment was not required.

The rack was made of steel and held four panels. (See Appendix, part J for details of rack.) The rack itself was not insulated in order to favor deposition of as uniform thickness as possible on the panels, and the rack was stripped after each set of four panels was run.

Anode and rack locations were carefully marked on their respective rods, and the anode-to-cathode rod distance was fixed. Anodes were placed in the tank on the face side of the rack, but the back of all panels received some coating. The temperature of all plating solutions was automatically controlled to ±2 F.

Standardization of all plating baths was made by depositing individual metals directly on steel panels for magnegage readings. After the current density and time were approximately established in a given bath as shown by magnegage readings, a set of panels was then sectioned and microscopic thickness determinations made. The microscopic and the magnegage values were determined and correlation established before the panels were run. Only after good uniformity was obtained between five test locations on each panel and between comparable positions on the four panels were microscopic thickness checks for comparison and final standardization made. (See Appendix, part L for details of mask used for locating panel positions for thickness tests.) The thicknesses of the deposits on panels plated with buffed deposits of acid copper and Watt's nickel were measured by magnegage. Those panels were rejected on which the thicknesses of the deposits were below that desired. If the thicknesses of the deposits exceeded the value desired, the panels were rebuffed to the proper thickness.

TABLE II.—INSPECTION DATA—PROGRAM NO. 3 PANELS.

Lot	Steel (SAE)	Coating, mils				1.1 yr			
						Cleaned[a]		Uncleaned	
		Cyanide Copper	Thiourea Acid Copper	Nickel[b]	Total	Rating	Description	Rating	Description
KURE BEACH, N. C.									
No. 1	950	...	...	1.5	1.5	3	xcR; xB (all peeled)	2	xpR; scR; xRs
No. 2		0.2	0.8	0.5	1.5	4	xcR; sB	2	xcR; xRs; iB
No. 3		0.05	0.95	0.5	1.5	3	xcR; xB	2	xcR; xRs; iB
No. 4		0.05	0.45	1.0	1.5	3	xcR; xB	2	xcR; xRs; iB
No. 5		0.2	0.3	1.0	1.5	4	xcR; sB	2	xcR; xRs; iB
No. 6		0.05	0.45	1.0	1.5	5	scR; iRs	7	vscR; ipR; sRs
No. 7		0.1	...	1.4	1.5	8	vscR; sB; sRs	7	vscR; ipR; sRs
NEW YORK, N. Y.									
No. 1	950	...	...	1.5	1.5	8	sB; vsW	8	sB
No. 2		0.2	0.8	0.5	1.5	8	sB; sW	8	sB; sW
No. 3		0.05	0.95	0.5	1.5	8	sB; sW	7	sB; sW
No. 4		0.05	0.45	1.0	1.5	5	iW; xB	5	xB; iW; scR
No. 5		0.2	0.3	1.0	1.5	8	iW; sB	8	iW; spR
No. 6		0.05	0.45	1.0	1.5	8	vspR; vsRs	8	spR; sRs
No. 7		0.1	...	1.4	1.5	8	vsRs	8	vsRs
DETROIT, MICH.									
									Downgraded due to peeling and large blisters (lot No. 1)
No. 1	950	...	...	1.5	1.5	6	ipR; iRs	2	xmxB; xeF; iRs
No. 2		0.2	0.8	0.5	1.5	7	spR; sSp; ssB; seF	8	spR; ivsB; vsRs
No. 3		0.05	0.95	0.5	1.5	7	ipR; ssB; sSp; sRs	6	spR; iiB
No. 4		0.05	0.45	1.0	1.5	7	spR; vscR; sSp; ssB	7	spR; isB
No. 5		0.2	0.3	1.0	1.5	8	spR; sSp; svsB; seF	8	spR; ieF; vssB
No. 6		0.05	0.45	1.0	1.5	9	iSp	9	iSp; vseR
No. 7		0.1	...	1.4	1.5	9	iSp	9	iSp; vseR

[a] Cleaned panels at Kure Beach not cleaned immediately prior to inspection.
[b] Lots Nos. 1 to 5 are bright nickel; lots Nos. 6 and 7 are Watt's nickel.

Inspection Results:

Table II presents the inspection data on the Program No. 3 panels after 1.1 yr of weather exposure at the locations designated. This inspection data is based on the so-called "old method" of rating, which has been used by Subcommittee II for several years. This method makes use of the photographic observational standards included in the Subcommittee II report for 1949[2] (pp. 226–238).

The system of abbreviations used to supplement the rating number record and to define the types of deterioration is given below:

TYPES OF FAILURE

R = Corrosion (rusting) of the basis metal. (Permanent or massive type of basis metal corrosion such as that in pinholes, bare or flaked areas, or in craters of broken blisters.)

R_s = Stain due to basis metal corrosion products, such as rust stain, which can be removed readily with a damp cloth or chamois and mild abrasive revealing a sound bright surface.

S = Stains or spots other than that of *obvious* basis metal corrosion products.

S_p = Surface pits. Corrosion pits probably not extending through to the basis metal—

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[2] *Proceedings*, Am. Soc. Testing Mats., Vol. 49, p. 220 (1949).

that is, absence of *obvious* basis metal corrosion products bleeding therefrom.

F = Flaking or peeling of deposit.
B = Blistering.
C = Cracking.
Z = Crazing.
W = Crow's feet.

Degree of Extent of Pinhole Rusting, Staining, Surface Pitting, Flaking, etc.

vs = very slight amount.
s = slight amount.
i = intermediate or moderate amount.
x = excessive amount.

Description of Blisters

s = less than about 0.5 mm in diameter.
i = about 0.5 to 2.0 mm in diameter.
x = greater than about 2.0 mm in diameter.
vf = 5 or fewer.
f = 5+ to 25.
i = 10+ to 25.
m = 25+ to 50.
vm = over 50.

Description of Location of Defects

e = edge
g = general

Examples

(1) ipR, vscR, sRs = a moderate amount of pin-point-type rusting, a very slight amount of crater-type rusting, and a slight amount of rust stain which can be readily removed.

(2) iSp, iS, iiW, seZ = moderate surface pitting, moderate staining (other than rust), an intermediate number of moderate size crow's feet, a small amount of edge crazing.

(3) xcR, xRs = excessive crater-type rust spots and an excessive amount of removable rust over a sound, bright surface.

Tables III and IV present inspection data on the same panels obtained by the rating method tentatively approved as suggested by Section D of Subcommittee II. This new rating method was published as a part of the report of Committee B-8 in 1953.[1]

It is to be pointed out that, in conformance with the recommendations of Section A, the individual lots, consisting of eight panels each, were randomly divided into two groups, one of which was continuously exposed at all locations with no cleaning. The other group was regularly cleaned once each month by rubbing with a water paste of Johns-Manville Super Floss (2 to 4 μ diatomaceous earth), allowing the paste to dry, and removing with a soft, dry cloth.

Conclusions:

Within the range of variables represented by the test panels and their method of exposure, the following indicated conclusions appear to be warranted through a study of the data in Tables II, III, and IV:

1. The effect of the thickness of the cyanide copper flash deposited under the acid copper coating appears to be slight and thus tends to validate the conclusions drawn from Program No. 1,[3] but where a difference exists, it is in favor of the heavier flash coating. The results, however, would not appear to account for the marked differences noted in the effect of the thickness of the copper flash observed when comparing Program No. 1 with Program No. 2.

2. In a seacoast atmosphere, where "protective value" as opposed to "surface pitting" is the principal factor revealed, Watt's nickel coatings (lots Nos. 6 and 7) appear to be markedly superior to "bright" nickel coatings (lots Nos. 1 through 5 inclusive). This is true for both the all "bright" nickel coating (lot No. 1) and the combination copper-nickel ones (lots Nos. 2 through 5 inclusive). Any similar differences warranting the drawing of conclusions have not become apparent in industrial atmospheres.

3. Except for some scattered results, there appears to be little effect of cleaning the panels on the progress of their deterioration.

4. As far as the rating numbers are concerned, there is, practically speaking, remarkably good agreement between the old rating system and the new one.

5. A comparison of the exposure data from the three sites shows that, within the limitation of time of exposure, the seacoast atmosphere at Kure Beach was very much more destructive than were

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[3] *Proceedings*, Am. Soc. Testing Mats., Vol. 51, p. 204 (1951).

TABLE III.—SUMMARY OF RESULTS OF SECTION D RATINGS OF PROGRAM NO. 3 COPPER-NICKEL-CHROMIUM PLATED STEEL AFTER 12 MONTHS' EXPOSURE.

Lot	Plating Thickness, mils			Kure Beach, N. C.			New York, N. Y.			Detroit, Mich.		
	Cyanide Copper	Acid Copper	Nickel[a]	Not Cleaned	Before Cleaning	After Cleaning	Not Cleaned	Before Cleaning	After Cleaning	Not Cleaned	Before Cleaning	After Cleaning
No. 1			1.5	4.0	2.3		7.4	6.4		2.1	8.2	10.0
			1.5	4.4	1.6		7.2	10.0		1.6	7.8	10.0
			1.5	4.0	0		7.6	10.0		2.1	7.7	10.0
			1.5	6.4	0		7.6	6.4		1.6	7.3	10.0
Average				4.7	1.0		7.5	8.2		1.75	7.75	10.0
No. 2	0.2	0.8	0.5	3.1	3.0		4.2	6.3		8.9	8.6	9.0
	0.2	0.8	0.5	3.1	4.2		6.3	6.3		8.0	7.8	8.0
	0.2	0.8	0.5	3.1	5.1		6.3	4.2		9.5	4.2	4.2
	0.2	0.8	0.5	3.1	2.4		6.3	6.3		9.5	8.0	8.0
Average				3.1	3.7		5.8	5.8		9.0	7.1	7.3
No. 3	0.05	0.95	0.5	3.1	1.3		4.6	4.2		10.0	8.0	8.0
	0.05	0.95	0.5	3.1	1.7		4.5	4.2		9.5	7.5	7.8
	0.05	0.95	0.5	2.8	1.8		4.6	4.2		3.9	7.8	8.0
	0.05	0.95	0.5	3.1	1.9		4.6	4.2		3.9	7.5	7.8
Average				3.0	1.7		4.6	4.2		6.8	7.7	7.9
No. 4	0.05	0.45	1.0	4.4	3.6		5.1	3.3		10.0	7.4	8.0
	0.05	0.45	1.0	2.8	3.2		9.6	3.3		3.5	7.2	7.6
	0.05	0.45	1.0	3.5	2.1		10.0	9.0		8.0		
	0.05	0.45	1.0	2.8	3.2		9.2	7.2		6.9	7.6	8.0
Average				3.4	3.0		8.4	5.7		7.1	7.4	7.9
No. 5	0.2	0.3	1.0	3.1	4.2		9.4	10.0		9.9	4.8	4.8
	0.2	0.3	1.0	2.8	3.6		9.2	9.0		4.5	8.4	8.4
	0.2	0.3	1.0	3.1	5.0		10.0	9.4		4.7	7.8	7.8
	0.2	0.3	1.0	4.8	3.6		9.2	10.0		9.9	8.8	8.8
Average				3.55	4.1		9.5	9.6		7.2	7.45	7.45
No. 6	0.05	0.45	1.0	7.9	6.4		9.0	8.1		9.0	9.0	9.0
	0.05	0.45	1.0	6.6	8.0		9.0	8.8		8.8	9.0	9.0
	0.05	0.45	1.0	8.6	8.0		10.0	9.0		8.8	9.0	9.0
	0.05	0.45	1.0	10.0	7.0		8.7	8.8		9.0	9.0	9.0
Average				8.3	7.35		9.2	8.7		8.9	9.0	9.0
No. 7	0.1		1.4	7.7	8.4		10.0	9.0		8.8	9.0	9.0
	0.1		1.4	9.4	9.9		9.3	9.3		8.5	9.0	9.0
	0.1		1.4	7.7	7.7		9.0	9.3		8.8	9.0	9.0
	0.1		1.4	8.4	8.0		10.0	9.3		9.0	9.0	9.0
Average				8.3	8.5		9.6	9.3		8.8	9.0	9.0

[a] Lots Nos. 1 to 5 are bright nickel; lots Nos. 6 and 7 are Watt's nickel.

the environments at New York City and Detroit, which appear to be about equal at the end of 1.1 yr. It is interesting in this regard to examine the shorthand description of the condition of the panels as listed in the old rating method. It will be noted that at Kure Beach virtually all panels have a greater or less extent of pinhole and crater rusting, which is present to a much lesser degree in Detroit and virtually absent in New York City.[4]

Largely for purpose of record, Table

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[4] It should be remarked that the Detroit environment is especially severe at street level. The exposure site was at a higher elevation. (From A. E. S. Project 15 data.)

TABLE IV.—RESULTS OF SECTION D RATINGS OF PROGRAM NO. 3. COPPER-NICKEL-CHROMIUM PLATED STEEL PANELS.

Panel	Variables, Plating Thickness, mils	Rating	Total Weighted Area	Per Cent of Area Defective for Each Type of Defect												Remarks
				Light Stain	Moderate Stain	Dark Stain	Surface Pitting	Crow's Feet	Crazing	Cracking	Basis Metal Corrosion Stain	Pin-Point Corrosion	Flaking	Blistering	Crater Corrosion	
12-MONTHS' ATMOSPHERIC EXPOSURE AT KURE BEACH—PANELS NOT CLEANED OTHER THAN WATER RINSING FOR INSPECTION																
Weighting factor........................				0.01	0.1	1.0	0.1	0.1	0.01	0.01	0.1	1	4	2	4	
No. 1-13....	1.5 bright nickel	4.0	4.85	35	12.0							0.5			0.7	0.6eRs
No. 1-14....		4.4	3.5	25	10.0							0.25			0.5	0.5eRs
No. 1-15....		4.0	4.85	35	12.0							0.5			0.7	0.5eRs
No. 1-16....		6.4	0.75	25	5.0							0.25			0.05	
Average...		4.7														
No. 2-13....	(0.2 cyanide copper)	3.1	9.15	15	10										2	3.0eRs
No. 2-14....	(0.8 thiourea acid copper)	3.1	9.15	15	10										2	3.0eRs
No. 2-15....	(0.5 bright nickel)	3.1	9.15	15	10										2	3.0eRs
No. 2-16....	(0.01 chromium)	3.1	9.15	15	10										2	3.0eRs
Average...		3.1														
No. 3-13....	(0.05 cyanide copper)	3.1	9.15	15	10										2.0	3.0eRs
No. 3-15....	(0.95 thiourea acid copper)	3.1	9.15	15	10										2.0	3.0eRs
No. 3-15....	(0.5 bright nickel)	2.8	11.55	5	15										2.5	2.0eRs
No. 3-16....	(0.01 chromium)	3.1	9.15	15	10										2.0	2.0eRs
Average...		3.0														
No. 4-13....	(0.05 cyanide copper)	4.4	3.50	1.0	7										0.7	1.0eRs
No. 4-14....	(0.45 thiourea acid copper)	2.8	11.55	5.0	15										2.5	2.0eRs
No. 4-15....	(1.0 bright nickel)	3.5	7.02	2.0	10										1.5	2.0eRs
No. 4-16....	(0.01 chromium)	2.8	11.55	5.0	15										2.5	2.0eRs
Average...		3.4														
No. 5-13....	(0.2 cyanide copper)	3.1	9.15	15.0	10.0										2.0	3.0eRs
No. 5-14....	(0.3 thiourea acid copper)	2.8	11.55	5.0	15.0										2.5	2.0eRs
No. 5-15....	(1.0 bright nickel)	3.1	9.15	15.0	10.0										2.0	3.0eRs
No. 5-16....	(0.01 chromium)	4.8	2.51	1.0	5.0										0.5	1.0eRs
Average...		3.55														

No. 6-13....	(0.05 cyanide copper)	7.9	0.23	4.0	0.5							0.10		0.02		3.0eRs + eB
No. 6-14....	(0.45 acid copper)	6.6	0.61	25.0	5.0							0.25	0.01	0.01		2.0eRs + eB
No. 6-15....	(1.0 Watt's nickel)	8.6	0.13	3.0	0.5							0.05				1.0eRs + eB
No. 6-16....	(0.01 chromium)	10.0	0.04	0.05	0.2							0.02				2.0eRs + eB
Average...		8.3														
No. 7-13....	(0.1 cyanide copper)	7.7	0.27	5.0	0.7							0.15				1.0eRs
No. 7-14....	(1.4 Watt's nickel)	9.4	0.07	1.0	0.2							0.05				2.0eRs + eB
No. 7-15....	(0.01 chromium)	7.7	0.27	5.0	0.7							0.15				1.0eRs
No. 7-16....		8.4	0.16	3.0	0.5							0.08				1.0eRs
Average...		8.3														

12-MONTHS' ATMOSPHERIC EXPOSURE AT KURE BEACH BEFORE CLEANING—PANELS CLEANED PERIODICALLY WITH MILD ABRASIVE AND WATER

Weighting factor......................				0.01	0.1	1.0	0.1	0.1	0.01	0.01	0.01	1	4	2	4	
No. 1-9.....	1.5 bright nickel	2.3	16.75	0.1							5.0	0.25		3.0	2.5	eB
No. 1-10....		1.6	27.7	2.0							5.0	0.20		7.5	3.0	
No. 1-11....		0	170								4.0			85.0		
No. 1-12....		0	170								4.0			85.0		
Average...		1.0														
No. 2-9.....	0.2 cyanide copper	3.0	10.15	2.5e							1.5				2.5	
No. 2-10....	0.8 thiourea acid copper	4.2	4.06	1.0e							0.6				1.0	
No. 2-11....	0.5 bright nickel	5.1	2.03	0.2e							0.3				0.5	
No. 2-12....	0.01 chromium	2.4	16.3	3.0e							3.0				4.0	
Average...		3.7														
No. 3-9.....	0.05 cyanide copper	1.3	36.4								4.0			10.0	4.0	
No. 3-10....	0.95 thiourea acid copper	1.7	26.3	2.5e							3.0			10.0	1.5	eB
No. 3-11....	0.5 bright nickel	1.8	25.3	3.0e							3.0			7.5	2.5	eB
No. 3-12....	0.01 chromium	1.9	23.3	3.0e							3.0			7.5	2.0	eB
Average...		1.7														
No. 4-9.....	0.05 cyanide copper	3.6	6.08	2.5e							0.8				1.5	
No. 4-10....	0.45 thiourea acid copper	3.2	8.1	2.5e							1.0				2.0	
No. 4-11....	1.0 bright nickel	2.1	20.3	3.0e							3.0			2.0	4.0	
No. 4-12....	0.01 chromium	3.2	8.1	3.0e							1.0				2.0	
Average...		3.0														

(Continued on pp. 324–330.)

TABLE IV.—*Continued.*

Panel	Variables, Plating Thickness, mils	Rating	Total Weighted Area	Per Cent of Area Defective for Each Type of Defect												Remarks
				Light Stain	Moderate Stain	Dark Stain	Surface Pitting	Crow's Feet	Crazing	Cracking	Basis Metal Corrosion Stain	Pin-Point Corrosion	Flaking	Blistering	Crater Corrosion	
12-MONTHS' ATMOSPHERIC EXPOSURE AT KURE BEACH BEFORE CLEANING—PANELS CLEANED PERIODICALLY WITH MILD ABRASIVE AND WATER—*Continued*																
Weighting factor				0.01	0.1	1.0	0.1	0.1	0.01	0.01	0.01	1	4	2	4	
No. 5-9	0.2 cyanide copper	4.2	4.06	2.5e							0.6				1.0	
No. 5-10	1.3 thiourea acid copper	3.6	6.08	1.0e							0.8				1.5	
No. 5-11	1.0 bright nickel	5.0	2.15	2.0e							0.5	0.10			0.5	
No. 5-12	0.01 chromium	3.6	6.08	2.5e							0.8				1.5	
Average		4.1														
No. 6-9	0.05 cyanide copper	6.4	0.74	2.5e							0.25	0.15		0.12		eB
No. 6-10	0 45 acid copper	8.0	0.21	1.0e							0.6	0.15				
No. 6-11	1.0 Watt's nickel	8.0	0.21	2.5e							0.3	0.10			0.02	
No. 6-12	0.01 chromium	7.0	0.46	0.25e							1.0	0.20		0.08		eB
Average		7.35														
No. 7-9	0.1 cyanide copper	8.4	0.16	0.01							0.2	0.04		0.05		eB + 0.1eB
No. 7-10	1.4 Watt's nickel	9.9	0.055	0.05							0.15	0.02		0.01		eB
No. 7-11	0.01 chromium	7.7	0.27								0.30	0.10		0.07		
No. 7-12		8.0	0.22	0.05							0.40	0.10		0.04		
Average		8.5														
12-MONTHS' ATMOSPHERIC EXPOSURE AT NEW YORK—PANELS NOT CLEANED EXCEPT RINSING PRIOR TO INSPECTIONS																
Weighting factor				0.01	0.1	1.0	0.1	0.1	0.01	0.01	0.1	1	4	2	4	
No. 1-17	1.5 bright nickel	7.4	0.35									0.35				
No. 1-18		7.2	0.40									0.40				
No. 1-19		7.6	0.30									0.30				
No. 1-20		7.6	0.30									0.30				
Average		7.5														
No. 2-17	0.2 cyanide copper	4.2	4.00												1.0	1eCr; 1eRs
No. 2-18	0.8 thiourea acid copper	6.3	0.80												0.2	
No. 2-19	0.5 bright nickel	6.3	0.80												0.2	
No. 2-20	0.01 chromium	6.3	0.80												0.2	1eCr
Average		5.8														

No. 3-17....	0.05 cyanide copper	4.6	2.8												0.70	1eRs
No. 3-18....	0.95 thiourea acid copper	4.5	3.2												0.80	2eRs
No. 3-19....	0.50 bright nickel	4.6	2.8												0.70	1eRs
No. 3-20....	0.01 chromium	4.6	2.8												0.70	1eRs
Average...		4.6														
No. 4-17....	0.05 cyanide copper	5.1	2.0												0.50	1eCr
No. 4-18....	0.95 thiourea acid copper	9.2	0.08					0.80								1eCr
No. 4-19....	0.50 bright nickel	10.0	0.04					0.20	2.0							
No. 4-20....	0.01 chromium	9.2	6.0												1.5	1eF; 1eCr
Average...		8.4														
No. 5-17....	0.2 cyanide copper	9.4	0.07					0.70								1eCr
No. 5-18....	1.3 thiourea acid copper	9.2	0.075					0.25	5							
No. 5-19....	1.0 bright nickel	10.0	0.04					0.25	1.5							
No. 5-20....	0.01 chromium	9.2	0.08					0.80								0.5eCr
Average...		9.5														
No. 6-17....	0.05 cyanide copper	9.0	0.10	1.0			9.0									0.5edS
No. 6-18....	0.45 acid copper	9.0	0.093	0.3			9.0									
No. 6-19....	1.0 Watt's nickel	10.0	0.045	0.5			4.0									
No. 6-20....	0.01 chromium	8.7	0.12	2.0			10.0									0.5emS
Average...		9.2														
No. 7-17....	0.1 cyanide copper	10.0	0.05				5.0									1e; 1S
No. 7-18....	1.4 Watt's nickel	9.3	0.075				7.5									1e; 1S
No. 7-19....	0.01 chromium	9.0	0.10				10.0									2emS
No. 7-20....		10.0	0.05				5.0									2eLs; 1eCr
Average...		9.6														

12-MONTHS' ATMOSPHERIC EXPOSURE AT NEW YORK BEFORE CLEANING—PANELS CLEANED PERIODICALLY WITH MILD ABRASIVE AND WATER

Weighting factor......................				0.01	0.05	0.1	0.01	0.1	0.01	0.01	0.1	1	4	2	4	
No. 1-21....	1.5 bright nickel	6.4	0.70					0.25				0.7				
No. 1-22....		10.0	0.025					0.50								
No. 1-23....		10.0	0.05													1.0eCr
No. 1-24....		6.4	0.70									0.7				0.5eCr
Average...		8.2														
No. 2-21....	0.2 cyanide copper	6.3	0.80												0.2	0.25eMs
No. 2-22....	0.8 thiourea acid copper	6.3	0.80												0.2	1.0eCr
No. 2-23....	0.5 bright nickel	4.2	4.0												1.0	2eCr
No. 2-24....	0.01 chromium	6.3	0.80												0.2	0.5eLs; 1.0eCr
Average...		5.8														

(Continued on pp. 326–330.)

TABLE IV.—*Continued.*

Panel	Variables, Plating Thickness, mils	Rating	Total Weighted Area	Per Cent of Area Defective for Each Type of Defect												Remarks
				Light Stain	Moderate Stain	Dark Stain	Surface Pitting	Crow's Feet	Crazing	Cracking	Basis Metal Corrosion Stain	Pin-Point Corrosion	Flaking	Blistering	Crater Corrosion	
12-MONTHS' ATMOSPHERIC EXPOSURE AT NEW YORK BEFORE CLEANING—PANELS CLEANED PERIODICALLY WITH MILD ABRASIVE AND WATER—*Continued*																
Weighting factors				0.01			0.01		0.01		0.1	1.0	4	2		
No. 3-21	0.05 cyanide copper	4.2	4.0												1.0	0.5eCr
No. 3-22	0.95 thiourea acid copper	4.2	4.0												1.0	0.5eCr; 0.5eLs
No. 3-23	0.5 bright nickel	4.2	4.0												1.0	
No. 3-24	0.01 chromium	4.2	4.0												1.0	0.5eCr
Average		4.2														
No. 4-21	0.05 cyanide copper	3.3	8.0					0.1							2.0	2.0eCr; 0.25eF
No. 4-22	0.45 thiourea acid copper	3.3	8.0					0.1							2.0	1.0eCr; 0.1eF
No. 4-23	1.0 bright nickel	9.0	0.10													0.5eCr
No. 4-24	0.01 chromium	7.2	0.41												0.1	0.5eCr
Average		5.7														
No. 5-21	0.2 cyanide copper	10.0	0.03					0.3								0.5eCr
No. 5-22	1.3 thiourea acid copper	9.0	0.1					1.0								0.5eCr
No. 5-23	1.0 bright nickel	9.4	0.07					0.7								0.5eCr
No. 5-24	0.01 chromium	10.0	0.03					0.3								1.0eCr
Average		9.6														
No. 6-21	0.05 cyanide copper	8.1	0.195	2.0			7.5					0.1				
No. 6-22	0.45 acid copper	8.8	0.115			0.05	10.0					0.01				
No. 6-23	1.0 Watt's nickel	9.0	0.11		0.25		10.0									
No. 6-24	0.01 chromium	8.8	0.116			0.05	10.0					0.01				
Average		8.7														
No. 7-21	0.1 cyanide copper	9.0	0.10				10.0									
No. 7-22	1.4 Watt's nickel	9.3	0.075				7.5									
No. 7-23	0.01 chromium	9.3	0.075				7.5									
No. 7-24		9.3	0.075				7.5									
Average		9.3														

12-MONTHS' ATMOSPHERIC EXPOSURE IN DETROIT—PANELS NOT CLEANED EXCEPT FOR WATER RINSING AT INSPECTIONS

Weighting factor				0.01			0.01		0.01		0.1	1.0	4	2		
No. 1-5	1.5 bright nickel	2.1	20.0											2.0		
No. 1-6	0.01 chromium	1.6	30.0											10.0		
No. 1-7		2.1	20.0											5.0		
No. 1-8		1.6	30.0											10.0		
Average		1.75												15.0		
No. 2-5	0.2 cyanide copper	8.9	0.111	1.0			0.1		0.01					0.05		
No. 2-6	0.8 thiourea acid copper	8.0	0.210	1.0			0.1		0.01					0.1		
No. 2-7	0.5 bright nickel	9.5	0.071	1.0			0.1		0.01					0.03		
No. 2-8	0.01 chromium	9.5	0.072	1.0			0.15							0.03		
Average		8.97														
No. 3-5	0.05 cyanide copper	10.0	0.031	1.0			0.1							0.01		
No. 3-6	0.95 thiourea acid copper	9.5	0.071	1.0			0.1							0.03		
No. 3-7	0.5 bright nickel	3.9	5.00	0.5			0.05							2.5		
No. 3-8	0.01 chromium	3.9	5.01	1.0			0.1							2.5		
Average		6.8														
No. 4-5	0.05 cyanide copper	10.0	0.021				0.1					0.001		0.01		
No. 4-6	0.45 thiourea acid copper	3.5	7.01	1.0			0.1		0.01					3.5		
No. 4-7	1.0 bright nickel	8.0	0.212	1.0			0.15		0.01					0.10		
No. 4-8	0.01 chromium	6.9	0.511	1.0			0.1							0.25		
Average		7.1														
No. 5-5	0.2 cyanide copper	9.9	0.051	1.0			0.1		0.01					0.02		
No. 5-6	0.3 thiourea acid copper	4.5	3.23	1.0			0.1		0.01				0.8	0.01		
No. 5-7	1.0 bright nickel	4.7	2.83	1.0			0.05		0.01				0.7	0.10		
No. 5-8	0.01 chromium	9.9	0.05	1.0			0.05							0.02		
Average		7.2														
No. 6-5	0.05 cyanide copper	9.0	0.10				10.0									
No. 6-6	0.45 acid copper	8.8	0.12				12.0									
No. 6-7	1.0 Watt's nickel	8.8	0.12				12.0									
No. 6-8	0.01 chromium	9.0	0.10				10.0									
Average		8.9														
No. 7-5	0.1 cyanide copper	8.8	0.12				12.0									
No. 7-6	1.4 Watt's nickel	8.5	0.15	1.0			13.0				0.1					
No. 7-7	0.01 chromium	8.8	0.12				12.0									
No. 7-8		9.0	0.10				10.0									
Average		8.8														

(Continued on pp. 328–330.)

TABLE IV.—*Continued.*

Panel	Variables, Plating Thickness, mils	Rating	Total Weighted Area	Defective for Each Type of Defect												Remarks
				Light Stain	Moderate Stain	Dark Stain	Surface Pitting	Crow's Feet	Crazing	Cracking	Basis Metal Corrosion Stain	Pin-Point Corrosion	Flaking	Blistering	Crater Corrosion	
12-MONTHS' ATMOSPHERIC EXPOSURE IN DETROIT BEFORE CLEANING—PANELS CLEANED PERIODICALLY WITH MILD ABRASIVE AND WATER																
Weighting factor				0.01			0.01		0.01		0.1	1	4	2		
No. 1-1	1.5 bright nickel	8.2	0.185	1.0							0.25	0.15				
No. 1-2		7.8	0.26	2.0							0.4	0.20				
No. 1-3		7.7	0.27	1.0							0.5	0.20				
No. 1-4		7.3	0.37	2.0							1.0	0.25				
Average		7.75														
No. 2-1	0.2 cyanide copper	8.6	0.141	1.0			0.1				0.1	0.02		0.05		
No. 2-2	0.8 thiourea acid copper	7.8	0.255	2.0			0.1				0.05	0.02		0.1		
No. 2-3	0.5 bright nickel	4.2	4.23	1.0			0.1				0.2	0.1	1.0	0.05		
No. 2-4	0.01 chromium	8.0	0.221	1.0			0.1		0.02		0.1			0.1		
Average		7.7														
No. 3-1	0.05 cyanide copper	8.0	0.211	1.0			0.1		0.005					0.1		
No. 3-2	0.95 thiourea acid copper	7.5	0.326	2.0			0.1		0.01		0.15	0.05		0.12		
No. 3-3	0.5 bright nickel	7.8	0.246	1.0			0.1		0.01		0.05	0.03		0.1		
No. 3-4	0.01 chromium	7.5	0.318	2.0			0.1				0.07	0.05		0.12		
Average		7.7														
No. 4-1	0.05 cyanide copper	7.4	0.352	2.5			0.15				0.25	0.1		0.1		
No. 4-2	0.45 thiourea acid copper	7.2	0.387	2.5			0.15				0.1	0.05		0.15		
No. 4-3	1.0 bright nickel															
No. 4-4	0.01 chromium	7.6	0.291	2.5			0.1		0.01		0.15	0.05		0.1		
Average		7.4														
No. 5-1	0.2 cyanide copper	4.8	2.66	2.0			0.05				0.1	0.03	0.6	0.1		
No. 5-2	0.3 thiourea acid copper	8.4	0.156	3.0			0.05		0.01		0.15	0.07		0.02		
No. 5-3	1.0 bright nickel	7.8	0.241	2.0			0.1				0.1	0.07		0.07		
No. 5-4	0.01 chromium	8.8	0.115	1.0							0.05			0.05		
Average		7.45														

No. 6-1.....	0.05 cyanide copper	9.0	0.10				10.0									
No. 6-2.....	0.45 acid copper	9.0	0.10				10.0									
No. 6-3.....	1.0 Watt's nickel	9.0	0.10				10.0									
No. 6-4.....	0.01 chromium	9.0	0.10				10.0									
Average...		9.0														
No. 7-1.....	0.1 cyanide copper	9.0	0.10				10.0									
No. 7-2.....	1.4 Watt's nickel	9.0	0.10				10.0									
No. 7-3.....	0.01 chromium	9.0	0.10				10.0									
No. 7-4.....		9.0	0.10				10.0									
Average...		9.0														

12-MONTHS' ATMOSPHERIC EXPOSURE IN DETROIT AFTER CLEANING—PANELS CLEANED PERIODICALLY WITH ABRASIVE AND WATER

Weighting factor........................				0.01	0.1	1.0	0.1	0.1	0.01	0.01	0.1	1	4	2	4	
No. 1-1.....	1.5 bright nickel	10.0	0.001				0.05									
No. 1-2.....		10.0	0.001				0.05									
No. 1-3.....		10.0	0.001				0.05									
No. 1-4.....		10.0	0.001				0.05									
Average...		10.0														
No. 2-1.....	0.2 cyanide copper	9.0	0.100				0.02							0.05		
No. 2-2.....	0.8 thiourea acid copper	8.0	0.200				0.02							0.1		
No. 2-3.....	0.5 bright nickel	4.2	4.10				0.015						1.0	0.05		
No. 2-4.....	0.01 chromium	8.0	0.200				0.03		0.02					0.1		
Average...		7.3														
No. 3-1.....	0.05 cyanide copper	8.0	0.200				0.02		0.005					0.1		
No. 3-2.....	0.95 thiourea acid copper	7.8	0.240				0.01		0.01					0.12		
No. 3-3.....	0.5 bright nickel	8.0	0.200				0.02		0.01					0.1		
No. 3-4.....	0.01 chromium	7.8	0.240				0.02							0.12		
Average...		6.4														
No. 4-1.....	0.05 cyanide copper	8.0	0.200				0.01							0.1		
No. 4-2.....	0.45 thiourea acid copper	7.6	0.300				0.01							0.15		
No. 4-3.....	1.0 bright nickel															
No. 4-4.....	0.01 chromium	8.0	0.200				0.01							0.1		
Average...		7.9														

(Continued on p. 330.)

TABLE IV.—*Concluded*

Panel	Variables, Plating Thickness, mils	Rating	Total Weighted Area	Per Cent of Area Defective for Each Type of Defect												Remarks
				Light Stain	Moderate Stain	Dark Stain	Surface Pitting	Crow's Feet	Crazing	Cracking	Basis Metal Corrosion Stain	Pin-Point Corrosion	Flaking	Blistering	Crater Corrosion	
12-MONTHS' ATMOSPHERIC EXPOSURE IN DETROIT AFTER CLEANING—PANELS CLEANED PERIODICALLY WITH ABRASIVE AND WATER—*Continued*																
No. 5-1.....	0.2 cyanide copper	3.6	6.51				0.05						1.6	0.1		
No. 5-2.....	1.3 thiourea acid copper	10.0	0.041				0.05							0.02		
No. 5-3.....	1.0 bright nickel	8.6	0.141				0.05							0.07		
No. 5-4.....	0.01 chromium	9.0	0.101				0.05							0.05		
Average...		7.8														
No. 6-1.....	0.05 cyanide copper	9.0	0.100				10.0									
No. 6-2.....	0.45 acid copper	9.0	0.100				10.0									
No. 6-3.....	1.0 Watt's nickel	9.0	0.100				10.0									
No. 6-4.....	0.01 chromium	9.0	0.100				10.0									
Average...		9.0														
No. 7-1.....	0.1 cyanide copper	9.0	0.100				10.0									
No. 7-2.....	1.4 Watt's nickel	9.0	0.100				10.0									
No. 7-3.....	0.01 chromium	9.0	0.100				10.0									
No. 7-4.....		9.0	0.100				10.0									
Average...		9.0														

TABLE V.—INSPECTION DATA—PROGRAM NO. 1 PANELS AT STATE COLLEGE, PA.

Lot	Steel (SAE)	Coating, mils			6.2 yr		7.2 yr	
		Copper	Nickel[a]	Total	Rating	Description	Rating	Description
No. 1	1095	...	1.0	1.0	3	xpR; icR; vsB	3	xpR; iRs; icR
No. 2		0.1	0.9	1.0	4	icR; spR; sB	2	xcR ; xpR; xsB; iRs
No. 3		0.5	0.5	1.0	0	xcR; xRs; iB	0	xcR; xRs
No. 4		0.5(b)	0.5	1.0	1	xcR; xRs; iB	0	xcR; xRs
No. 4NA		...	0.5(b) +0.5	1.0	7	spR; xcR	5	ipR; isB; scR
No. 4B		...	0.5(ba) +0.5	1.0	10	vsSp	9	vspR
No. 5X		...	1.0(pH)	1.0	6	xpR; vscR; vsSp; vsRs	5	xpR; scR; vsRs
No. 6X		0.1	0.9(pH)	1.0	4	xcR; xB; vspR; vsRs	1	xcR; iRs; xB (worm tracks)
No. 5	1095	...	1.5	1.5	8	ipR; vsB; vsSp	7	ipR; sRs
No. 6		0.1	1.4	1.5	9	vscR; sB; vsSp	7	ipR; isB; scR
No. 7		0.5	1.0	1.5	6	icR; iB	2	xcR; xsB; spR
No. 8		1.0	0.5(WA)	1.5	2	xcR; xB; iRs; sSp; spR	0	xcR; xRs (worm tracks)
No. 9		1.0(b)	0.5	1.5	4	xcR; iB; sRs	1	xcR; iRs; xsB
No. 9NA		...	−1.0(b) +0.5	1.5	9	spR; sSp; seZ; vsB	9	ivsB
No. 10		...	2.0	2.0	9	vspR; sSp; seZ	9	vspR
No. 11		0.1	1.9	2.0	10	sSp	9	svsB
No. 12		0.5	1.5	2.0	10	sSp	9	svsB
No. 13		1.0	1.0	2.0	10	sSp	9	ivsB
No. 14		1.0(b)	1.0	2.0	9	vscR; vsB; sSp	8	icR; isB
No. 14NA		...	1.0(b) +1.0	2.0	10	sSp	10	
No. 14B		...	1.0(ba) +1.0	2.0	10	sSp	10	
No. 15		1.5	0.5	2.0	8	icR; iB; spR	6	icR; isB; sRs
No. 16		1.5(b)	0.5	2.0	9	scR; iB; vspR	7	scR; isB
No. 10X	1095	...	3.0	3.0	10	vsSp	10	
No. 14X		1.0	2.0	3.0	10	vsSp	10	
No. 16X		1.5	1.5	3.0	10	vsSp	10	
No. 25	4130	...	1.5	1.5	8	ipR; vsRs; vsSp	8	ipR
No. 26		0.1	1.4	1.5	10	vsSp	10	
No. 27		0.5	1.0	1.5	9	scR; vsSp; eR	8	scR; spR; isB
	1095				10(2)	iSp; xF; eR (indicates bad preparation)		Various stages of peeling; all different
No. 28		...	2.0(SB)	2.0	2(2)	xF	0–9	
No. 29		1.0	1.0(SB)	2.0	8	icR; iB; vsSp	7	xsB; vscR
No. 29NA		...	1.0(B) +1.0(SB)..	2.0	10	vsSp	9	ssB
No. 30	1095	1.0	1.0(B)	2.0	8	scR; xB; sSp	5	icR; xiB
No. 31		1.0(b)	1.0(B)	2.0	9	scR; xB	5	scR; xiB
No. 32		0.1	0.9 +1.0(B)	2.0	9	xSp; spR; xW	7	xsW (downgraded due to S_p)
								xiW (downgraded due to S_p)
No. 33		0.1	0.9(b) +1.0(B)	2.0	8	spR; xW; Sp	7	xsW (downgraded due to S_p)
No. 34	1095 high polish	0.1	0.9(b) +1.0(B)	2.0	9	spR; xSp	8	

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[a] (b) = buffed; (ba) = buffed and annealed; (WA) = wetting agent present; (pH) = high pH bath; (SB) = semi-bright; (B) = bright.

V is included in this report to give the inspection data on the Program No. 1 panels that have been on continuous exposure at State College, Pa., for 7.2 yr. The data indicate no need for altering the conclusions that have been published in an earlier report.[1] It was, however, interesting to the group performing the inspection to note the type and extent of corrosion that occurs in the rural atmosphere at State College, which to all intents and purposes is free of "artificial" corrosive influences and the unusually severe conditions existing along the seashore. While the progress of deterioration occurs at an exceedingly slow rate, it was felt by the group making the inspection that State College should be continued as an exposure site for any future programs for the very reason that the conditions there are representative of inland, rural areas of the country where deterioration occurs only because of the acts of nature. A further interesting observation is that while deteriorations are relatively slow the comparative behavior of copper-nickel-chromium *versus* nickel-chromium coatings is in the same direction at State College as at Kure Beach.

TABLE VI.—INSPECTION DATA—PROGRAM NO. 2 PANELS.

Lot	Steel (SAE)	Coating, mils			3.4 yr	
		Copper[a]	Nickel	Total	Rating	Description
			NEW YORK, N. Y.			
No. 1......	950	...	1.0	1.0	2	xpR; xRs; xSp; ieZ
No. 2......		0.1 C	0.9	1.0	2	xpR; xRs; xSp; xcR; iB; ieF
No. 3......		...	1.5	1.5	2	xpR; xRs; xSp; xcR; ieF
No. 4......		0.1 C	1.4	1.5	5	spR; sRs; xSp; seZ; ieF
No. 5......		0.1 C + 0.4 A	1.0	1.5	4	spR; xSp; xecR; seZ; iW
No. 6......		0.2 C + 0.3 A	1.0	1.5	3	spR; xSp; xecR; seZ; iW
No. 7......		0.2 C	1.0	1.2	2	xSp; ipR; iRs; xcR; ieZ; ieF
No. 8......		0.5 C	1.0	1.5	4	scR; sRs; spR; xSp; ieF
No. 9......		0.5 P	1.0	1.5	6	xSp; sRs; spR; eZ
No. 10......		0.2 C + 0.3 A(b)	1.0	1.5	3	xSp; xpR; seZ; xRs
No. 11......		0.5 P(b)	1.0	1.5	6	xSp; sRs; spR; eZ
No. 1......	1010	...	1.5	1 5	1	xcR; xpR; xRs; iB; xSp
No. 2......		...	1.5[b]	1.5	2	xcR; xSp; ipR; iRs; eZ
No. 3......		...	1.5[c]	1.5	4	spR; scR; xSp; eZ; sRs; iW
			KURE BEACH, N. C.			
No. 1......	950	...	1.0	1.0	0	xF
No. 2......		0.1 C	0.9	1.0	1	xcR; xpR; xB; ieF; xRs
No. 3......		...	1.5	1.5	4	xpR; iRs; vscR; sB; xF
No. 4......		0.1 C	1.4	1.5	4	xpR; icR; sRs; iF; sB
No. 5......		0.1 C + 0.4 A	1.0	1.5	3	xcR; ipR; iRs; xB
No. 6......		0.2 C + 0.3 A	1.0	1.5	2	xcR; xpR; xRs; seF; xB
No. 7......		0.2 C	1.0	1.2	2	xpR; xRs; xcR; seF; xB
No. 8......		0.5 C	1.0	1.5	5	ipR; sRs; vscR; seF
No. 9......		0.5 P	1.0	1.5	4	icR; ipR; sRs; iB; eF
No. 10......		0.2 C + 0.3 A(b)	1.0	1.5	3	xcR; ipR; iRs; iB; eF
No. 11......		0.5 P(b)	1.0	1.5	4	scR; ipR; sRs; seF; sB
No. 1......	1010	...	1.5	1.5	3	icR; ipR; iRs; xSp; xeF
No. 2......		...	1.5[b]	1.5	3	icR; ipR; iRs; xSp; xeF
No. 3......		...	1.5[c]	1.5	2	xcR; sRs; ipR; xB; xF

[a] A = acid; C = cyanide; P = pyrophosphate; (b) = buffed.
[b] 10 mg Cu per liter.
[c] 25 mg Cu per liter.

There are a few panels in Program No. 1 to which special attention might be directed, specifically lots Nos. 4NA, 4B, 9NA, 14NA, and 14B. In comparison with other panels having equal thicknesses, each one of the above listed lots is at least equal to, with some far better than, any other lot numbers included in the test. It will be recalled that these are the lots where the nickel coatings were applied in two stages with either a buffing operation or an anneal and buff used between the two stages of metal deposition.

For purpose of record, Table VI is included in the report and presents the final ratings on the Program No. 2 panels, which had been on exposure at New York City and Kure Beach for 3.4 yr. It was the opinion of the inspection group that these panels had served their purpose, permitting their removal from the exposure racks.

As a part of the 1954 inspection tour, a meeting was held to discuss the merits of the two rating systems based on data which had just been gathered at Kure Beach and New York. The group recognized the similarity between the results obtained by the two rating methods, but it was felt that there was still need for refinement and for a rating method that would essentially be a compromise between the two. The one valid criticism of the new rating method was that it was too tedious and time-consuming; this might prove to be a formidable obstacle on any future program which conceivably might contain a considerably larger number of panels than are in Program No. 3. The principal criticism of the old method is involved in the necessity for carefully studying the shorthand description of the panels together with the rating numbers so as to arrive at a valid conclusion. For purpose of future guidance, it may be appropriate to point out at least one specific case which has annually resulted in some confusion and lack of agreement on the part of the inspectors.

At Kure Beach the predominant deteriorating influence is salt in the atmosphere. In New York City the predominant influence appears to be a condition of industrial environment which promotes an entirely different type of corrosion than at Kure Beach. In the environment at Kure Beach, the atmosphere promotes pinhole rusting, crater rusting, and rust stain. Such forms of deterioration occur, of course as a result of corrosion of the basis metal originating as a result of discontinuities existent or created in the protective metallic films. In New York the corrosive atmosphere is such as to attack the plated coatings and result in the formation of pits and what is designated as crow's feet, frequently without any sign of corrosion of the basis metal. Thus, one concept of the rating system could result in a low rating number being assigned to a panel in New York on which no rusting has occurred, and the same low rating number might be assigned one in Kure Beach because of considerable rusting. The question then arises: Is protective value being considered—that is, protection against rust of the basis metal—or is it the resistance of the coatings to chemical attack that is being considered, bearing in mind that the latter qualification is probably independent of manufacturing procedures? It was on this basis that the need was felt for a rating system that would be a compromise between the two that presently exist, one that would not be so time-consuming and yet would enable a reader to evaluate correctly the protective value of coatings from a table of numbers.

Another consideration discussed involved the recognition of the specific environments existent at each exposure site, attended therefore by a specific type of corrosion. Subcommittee II for some years has been in possession of

TABLE VII.—SUMMARY OF INSPECTION DATA ON THE ATMOSPHERIC EXPOSURE TESTS ON ELECTROPLATED LEAD COATINGS.

	Nominal Coating Thickness, mils	Number of Panels, Averaged	New York, N. Y.					
			Upper Surface			Under Surface		
			8.38 yr Average (1952)	9.33 yr Average (1953)	10.4 yr Average (1954)	8.38 yr Average	9.33 yr Average	10.4 yr Average
Sulfamate Pb on steel	0.50	3	70S	85S	70S–1R	30S	20S	100S–2R
	1.00	3	..	5S	5S	2S	10S	100S
Fluoborate Pb on steel	0.08	1	100R	100R	100R	100S–30R	100S–10R	100S–20R
	0.25	3	100S–75R	100S–50R	100S–60R	60S	50S–1R	100S–13R
	0.50	3	90S–6R	90S–5R	85S–11R	33S	20S–1R	100S–4R
	0.75	3	75S–1R	85S–3R	70S–7R	40S	20S	100S–5R
	1.00	3	10S–1R	6S	11S	25S	20S–1R	100S–2R
	2.00	5	...	5S	5S	...	10S	100S
Sulfamate Pb on Cu-plated steel	0.50	3	4S	5S	7S	15S	15S	100S–1R
	1.00	3	...	5S	5S	...	10S	100S
Fluoborate Pb on Cu-plated steel	0.08	1	100R	100R	100R	60R	100S–80R	100R
	0.25	3	95S–25R	95S–40R	100S–60R	10S	15S	100S–1R
	0.50	3	2S	5S	8S	6S	15S	100S
	0.75	3	3S	5S	5S–3R	...	10S	100S
	1.00	3	...	5S	7S	...	10S	100S
	2.00	5	...	5S	4S	...	10S	100S
Sulfamate Pb on sheet copper	0.25	3	Red stain	5S	6S	...	10S	100S
	0.50	3	...	5S	5S	...	10S	100S
Fluoborate Pb on sheet copper	0.25	3	Red stain	5S	7S	...	15S	100S
	0.50	3	...	5S	5S	...	15S	100S
Sulfamate Pb-Sn (2 per cent Sn) on steel	1.00	3	10S	10S	8S	...	10S	100S
Sulfamate Pb-Sn (10 per cent Sn) on steel	1.00	3	10S	10S	10S	...	10S	100S
Commercial hot-dipped terne (20 per cent Sn)	0.17	3	100S–80R	100S–60R	100S–70R	60S–3R	50S–8R	100S–10R
Commercial hot-dipped Pb (2.5 per cent Sn, 2 per cent Sb)	0.40	3	90S–65R	25S–70R	100S–70R	30S	20S	100S–2R
Electroplated zinc on steel	0.20	3	100R	100R	100R	100R	100R	100R
Hot-dipped zinc on steel	0.75	3	100R	100R	100R	100R	100R	100R
Fluoborate Pb on steel (damaged)	0.50	3	Spread	Spread	Spread	12S	20S	100S–1R
	1.00	3	Spread	Slight spread	Slight spread	3S	10S	100S
Fluoborate Pb on Cu-plated steel (damaged)	0.50	3	Slight spread	Slight spread	Slight spread	...	15S	100S
	1.00	3	Slight spread	Slight spread	Slight spread	...	10S	100S

	Nominal Coating Thickness, mils	Number of Panels, Averaged	State College, Pa.					
			Upper Surface			Under Surface		
			8.36 yr Average (1952)	9.25 yr Average (1953)	10.3 yr Average (1954)	8.36 yr Average	9.25 yr Average	10.3 yr Average
Sulfamate Pb on steel	0.50	0	...	...	...	...	...	...
	1.00	3	99S–95R	99S–98R	99S–98R	3P	3P	15P
Fluoborate Pb on steel	0.08	0	...	...	...	...	...	...
	0.25	0	...	...	...	...	...	...
	0.50	0	...	...	...	...	...	...
	0.75	0	...	...	...	...	...	...
	1.00	2	100S–98R	100S–98R	100S–99R	1P	3P	5P
	2.00	5	...	...	...	...	...	...
Sulfamate Pb on Cu-plated steel	0.50	0	...	...	...	...	...	...
	1.00	3	MP–1S	MP–1S–1R	2S–1R	2P	2P	5P
Fluoborate Pb on Cu-plated steel	0.08	0	...	...	...	...	...	...
	0.25	0	...	...	...	...	...	...
	0.50	0	...	...	...	...	...	...
	0.75	3	75S–50R	95S–80R	100S–99R	15P	MP–1S–1R	MP–1S
	1.00	3	MP–1S	MP–1S–1R	2S–1R	3P	8P–1S	10P
	2.00	5	...	...	...	...	...	...
Sulfamate Pb on sheet copper	0.25	3	50S	No Pb	No Pb	...	...	...
	0.50	3	...	No Pb	No Pb	...	...	...
Fluoborate Pb on sheet copper	0.25	3	40S	No Pb	No Pb	...	...	...
	0.50	3	...	No Pb	No Pb	...	...	...
Sulfamate Pb-Sn (2 per cent Sn) on steel	1.00	0	...	...	...	...	...	...
Sulfamate Pb-Sn (10 per cent Sn) on steel	1.00	1	100S–98R	100S–100R	100R	...	...	...
Commercial hot-dipped terne (20 per cent Sn)	0.17	0	...	...	...	...	...	...
Commercial hot-dipped Pb (2.5 per cent Sn-2 per cent Sb)	0.40	0	...	...	...	...	...	...
Electroplated zinc on steel	0.20	0	...	...	...	...	...	...
Hot-dipped zinc on steel	0.75	3	100S–25R	100S–50R	100S–90R	...	...	...
Fluoborate Pb on steel (damaged)	0.50	0	...	...	...	...	...	...
	1.00	3	Bad spread	Bad spread	Bad spread	...	4P	10P
Fluoborate Pb on Cu-plated steel (damaged)	0.50	0	...	...	...	...	...	...
	1.00	3	Spread	Bad spread	Bad spread	...	7P	10P

(Continued on pp. 336 and 337.)

TABLE VII.—*Continued.*

	Nominal Coating Thickness, mils	Number of Panels, Averaged	Kure Beach, N. C.					
			Upper Surface			Under Surface		
			8.27 yr Average (1952)	9.33 yr Average (1953)	10.4 yr Average (1954)	8.27 yr Average	9.33 yr Average	10.4 yr Average
Sulfamate Pb on steel	0.50	3	100R	100R	100R	100R	100R	100R
	1.00	3	98R	95R	95S–95R	50S–30R	50S–15R	50S–12R
Fluoborate Pb on steel	0.08	1	100R	100R	100R	100R	100R	100R
	0.25	3	100R	100R	100R	100R	100R	100R
	0.50	3	100R	100R	100R	100R	100R	100R
	0.75	3	100R	100R	100R	100R	100R	100R
	1.00	3	100R	100R	100R	100R	100R	100R
	2.00	5	20S–20R	20S–15R	20S–20R	50S–15R	20S–10R	20S–4R
Sulfamate Pb on Cu-plated steel	0.50	3	100R	100R	100R	95R	100S–90R	100R
	1.00	3	90S–8R	90S–80R	80S–70R	55S–12R	40S–10R	40S–10R
Fluoborate Pb on Cu-plated steel	0.08	1	100R	100R	100R	100R	100R	100R
	0.25	3	100R	100R	100R	100R	100R	100R
	0.50	3	100R	100R	100R	95R	95R	100R
	0.75	3	95R	95R	100R	50S–13R	50S–15R	60S–25R
	1.00	3	85S–80R	75S–60R	80S–75R	60S–30R	60S–40R	60S–12R
	2.00	5	15S–4R	5S–1R	4S–1R	30S–6R	20S–3R	10S–1R
Sulfamate Pb on sheet copper	0.25	3	No Pb	No Pb	No Pb	No Pb	No Pb	No Pb
	0.50	3	MP–15S(d)	50S(d)	60S(d)	20S(d)	10S(d)	20S(d)
Fluoborate Pb on sheet copper	0.25	3	No Pb	No Pb	No Pb	No Pb	No Pb	No Pb
	0.50	3	MP–15S(d)	50S(d)	95S(d)	10S(d)	20S(d)	10S(d)
Sulfamate Pb-Sn (2 per cent Sn) on steel	1.00	3	100R	100R	100R	95R	95R	100R
Sulfamate Pb-Sn (10 per cent Sn) on steel	1.00	3	100R	100R	100R	98S–80R	100S–50R	100S–50R
Commercial hot-dipped terne (20 per cent Sn)	0.17	3	100R	100R	100R	100R	100R	100R
Commercial hot-dipped Pb (2.5 per cent Sn, 2 per cent Sb)	0.40	3	100R	100R	100R	100R	100R	100R
Electroplated zinc on steel	0.20	3	100R	100R	100R	100R	100R	100R
Hot-dipped zinc on steel	0.75	3	45S–15R	25S–10R	100S–20R	. . .	5S–1R	5S–1R
Fluoborate Pb on steel (damaged)	0.50	3	100R	100R	100R	100R	100R	100R
	1.00	3	100R	100R	Bad spread	100R	100R	60S–30R
Fluoborate Pb on Cu-plated steel (damaged)	0.50	3	100R	100R	100R	100R	100R	100R
	1.00	3	Bad spread	45S–20R	Bad spread	Bad spread	35S–12R	80S–15R

	Nominal Coating Thickness, mils	Number of Panels, Averaged	Tela, Honduras	
			Upper Surface, 8.4 yr Average (1952)	Under Surface, 8.4 yr Average
Sulfamate Pb on steel	0.50	2	100R	100S–55R
	1.00	3	95R	5S–2R
Fluoborate Pb on steel	0.08	2	100R	100R
	0.25	3	100R	100R
	0.50	4	100R	100S–75R
	0.75	3	100R	95S–50R
	1.00	3	100R	50S–12R
	2.00	8	13S–2R	MP*
Sulfamate Pb on Cu-plated steel	0.50	0	...	...
	1.00	2	75S–30R	MP*
Fluoborate Pb on Cu-plated steel	0.08	1	100R	100R
	0.25	3	100R	100R
	0.50	3	100R	100S–60R
	0.75	1	100S–85R	MP*
	1.00	3	15S–2R	MP*
	2.00	8	MP*	MP*
Sulfamate Pb on sheet copper	0.25	3	No Pb	No Pb
	0.50	3	No Pb	MP–100S
Fluoborate Pb on sheet copper	0.25	3	No Pb	No Pb
	0.50	3	No Pb	MP–100S
Sulfamate Pb-Sn (2 per cent Sn) on steel	1.00	2	100R	100S–80R
Sulfamate Pb-Sn (10 per cent Sn) on steel	1.00	1	100R	100R
Commercial hot-dipped terne (20 per cent Sn)	0.17	3	100R	100R
Commercial hot-dipped Pb (2.5 per cent Sn, 2 per cent Sb)	0.40	1	100R	100R
Electroplated zinc on steel	0.20	1	100R	100R
Hot-dipped zinc on steel	0.75	3	90S–35R	MP*
Fluoborate Pb on steel (damaged)	0.50	2	100R	100R
	1.00	2	100R	100R
Fluoborate Pb on Cu-plated steel (damaged)	0.50	2	100R	100R
	1.00	2	Bad spread	MP*

Abbreviations and symbols used: P—number of pinholes, up to 25; MP—pinholes, more than 25; S—percentage of area stained, coating intact; R—percentage of flaky rust of base metal; (d)—dark; *—no significant corrosion.

NOTE.—Thickness of copper plate in all cases, 0.000015 in.

photographs showing various stages of corrosion typical of that occurring at Kure Beach; these have been used as a basis for assigning rating numbers. These photographs are also appropriately used in a rural atmosphere, but are of definitely questionable value for use in industrial atmospheres, such as are present in Detroit and New York. The group was in complete agreement that it should provide itself with panels that would show the various stages of deterioration at each exposure site. For this purpose the Subcommittee hopes to obtain several hundred standard plated panels that will be placed on exposure and removed at times appropriate to show the various stages of failure. It was further agreed that these panels should be retained at each exposure site for future use by inspection groups at the several locations.

ATMOSPHERIC EXPOSURE OF ELECTROPLATED LEAD AND ZINC COATINGS ON STEEL

The following report from the standpoint of visual inspection data is a continuation of the report for 1953;[1] from the standpoint of weight loss and tensile properties, it is a continuation of the report for 1949.[2]

Visual Inspection:

Table VII summarizes the visual inspection data for New York, N. Y., State College, Pa., Kure Beach, N. C., and Tela, Honduras, for roughly 8, 9, and 10 yr of exposure. No data were taken at Tela for the period from 4.30 to 8.40 yr, and at the latter time (1952) the panels were removed from Tela.

As mentioned in previous reports and shown in the 1953 report by rating ranges, the ratings are frequently open to question. For this reason a number of panels were again removed for steel weight and tensile strength loss in 1952, and as can be seen from that data in later sections, the results confirm the average visual inspection results.

Table VIII indicates that the important factor in corrosion protection offered by lead coatings is the thickness of the coating. A 1-mil coating on steel will offer good protection of the steel for 4 to over 10 yr depending on the location. The trend for a lead-coated steel panel has been to show very little (less than 5 per cent) rust for an induction period depending on the thickness. Then the breakdown or visible rusting will proceed at a more or less uniform rate to a value of 95 to 100 per cent visible rust. In general, but not invariably, the length of the breakdown period (the time interval between about 5 and 95 per cent visible rust) will be longer for those coatings which had the longer induction periods without visible rusting.

Table VIII gives the breakdown periods for pertinent coatings at three locations as determined from visual inspection data. It is only as accurate as the original data. It should be recognized that the data in Table VIII are based on visual inspection; actually 100 per cent rust represents a steel weight loss of considerably less than 0.1 g per sq in.

As can be seen from Table VIII, and as reported previously, the most severe of the three atmospheres for lead coatings is at Kure Beach and the least severe is at New York. Earlier visual inspection data showed, in most cases, less corrosion at Tela than at Kure Beach, but on the basis of visual inspection, steel and lead weight loss, and tensile strength loss data in the present report, it appears that the severity of the atmosphere at Tela compares with that at Kure Beach.

The retarding effect of a copper undercoat on the rate of rusting for lead-

TABLE VIII.—VISUAL INSPECTION BREAKDOWN PERIOD IN YEARS FOR UPPER SURFACES.

	Nominal Coating Thickness, mils	Kure Beach, N.C.	State College, Pa.	New York, N. Y.
Pb on steel	0.08	<0.8	<0.8– 1.0	<0.8– 1.0
	0.25	<0.8– 1.5	<0.8– 1.0	6.0–>9.0
	0.50	3.3– 4.0	2.0– 4.0	9.0–>9.0
	0.75	3.5– 4.0	5.0– 7.0	>9.0
	1.00	4.0– 7.0	6.0– 8.4	>9.0
Pb on Cu-flashed steel	0.08	<0.8	<0.8	<0.8– 1.0
	0.25	1.0– 3.0	1.0– 3.0	7.0–>9.0
	0.50	3.3– 4.4	5.0– 7.0	>9.0
	0.75	4.0– 6.0	7.5– 9.5	>9.0
	1.00	5.0– 10.0	>10.0	>9.0
Hot-dipped Pb on steel	0.4	<0.8– 4.0	1.0– 8.0	7.0– 9.0
Plated Zn on steel	0.20	<0.8– 1.8	1.5– 3.0	<0.8
Hot-dipped Zn on steel	0.75	8.0–>9.0	8.0–>9.0	2.0– 2.5

coated steel other than the 0.08-mil thickness is still evident.

The relative merit of lead and zinc depends, as would be expected, on the location of exposure. At New York lead is definitely more protective. At State College zinc is equal to or slightly better than lead. At Kure Beach the 0.75-mil hot-dipped zinc coating is more protective than an equal thickness of lead, but the thin deposit of plated zinc appears to be equivalent to that of lead on steel and inferior to that of lead on copper-flashed steel.

The degree of spread of corrosion on the "damaged" panels seems to be related more to the severity of the atmosphere than to whether the steel was or was not copper flashed prior to lead plating. The effect of the copper flash on the degree of spreading is inconsistent, but there is a slight but questionable tendency toward less spreading when the copper flash is used. One might expect, in view of the apparent steel corrosion acceleration caused by the copper flash under the extremely thin lead deposits, that the copper flash might accelerate spreading of corrosion on the damaged panels. This may have been offset in the visual examination of spreading by the beneficial effect of the copper flash on the general corrosion protection offered by heavier lead deposits.

TABLE IX.—ATMOSPHERIC CORROSION OF ELECTROPLATED LEAD.

Values are the average of data from six panels.

Exposure Time, yr	Initial Deposit Weight, g	Loss in Deposit Weight, g	Average Loss in Deposit Thickness, in.	Average Penetration, in. per yr
NEW YORK, N. Y.				
2.4	16.93	0.59	0.000066	0.000028
3.45	16.64	0.85	0.000095	0.000027
4.4	17.71	0.98	0.000109	0.000025
7.9	16.68	1.41	0.000158	0.00002
KURE BEACH, N. C.				
2.38	16.96	1.87	0.000210	0.000088
3.33	16.61	2.36	0.000260	0.000078
4.38	18.09	2.82	0.000317	0.000072
7.95	16.47	3.39	0.000380	0.000048
STATE COLLEGE, PA.				
2.28	17.14	1.51	0.000169	0.000074
3.25	16.85	1.67	0.000206	0.000063
4.28	17.11	2.11	0.000236	0.000055
7.87	16.87	2.96	0.000332	0.000042
TELA, HONDURAS				
2.27	17.18	1.52	0.000170	0.000075
4.30	16.71	2.28	0.000254	0.000060
8.5	17.36	3.58	0.000418	0.000049

When fine pores are present in lead coatings, the protection offered by lead has been attributed to both a sacrificial action and to its self-sealing property. In view of the relation between the protection offered to steel and the corrosion rate of lead itself at different sites, it would appear that the self-sealing action is of major importance compared to any sacrificial action of the lead.

TABLE XII.—STEEL CORROSION OF PANELS EXPOSED AT KURE BEACH, N. C. (10.7 Yr).

	Nominal Lead Coating Thickness, mils	Panel	Steel Weight Loss, g
Sulfamate lead on bare steel	0.50	No. 3	10.64
	1.00	No. 27	1.35
Fluoborate lead on bare steel	0.25	No. 51	24.97
	0.50	No. 75	9.40
	0.75	No. 111	4.57
	1.00	No. 137	3.37
Sulfamate lead on Cu-plated steel	0.50	No. 243	9.46
	1.00	No. 267	1.10
Fluoborate lead on Cu-plated steel	0.25	No. 291	29.63
	0.50	No. 317	10.24
	0.75	No. 351	3.59
	1.00	No. 375	0.64
	1.00	No. 377	0.77

Corrosion Rate of Lead:

Table IX and Fig. 1 present the weight loss of lead as determined from heavily lead-plated (2.00-mil) panels.

As stated in a previous report, the corrosion rate of lead is highly dependent on the type of atmosphere and decreases somewhat with time. It will be noticed also that there is an inverse relationship between the protective value of lead to steel and the corrosion rate of lead. For instance, at New York, where the corrosion rate for lead is the lowest, the protection offered by lead is the highest. In view of the relation between lead corrosion and protective value, it might be inferred that the breakdown period for various lead coatings at the same location would occur when the lead thickness reaches a certain minimum value. This does not seem to be the case. Considering the decrease in lead thickness with time, the heavier deposits, while giving longer protection, are of greater thickness when the breakdown occurs.

An attempt was made to determine the relative weight loss of lead on the upper and under surfaces. This was accomplished by first cleaning the panel and determining the total weight loss. The lead deposit was then stripped in stages from the under and upper surfaces. By this means, and knowing the original lead weight, it was possible to calculate the separate upper and under weight losses caused by exposure. This procedure presupposes that the thickness of lead on the front and back of the panels is the same. This assumption while nominally correct is not accurate enough for calculation when the weight loss is low. Table XIII presents the thickness losses due to exposure with respect to the upper and under surfaces for two panels at three exposure sites after approximately 10.7 yr of exposure. The discrepancy for the New York under surface demonstrates that the assumption of equal thickness on the front and back of panel is not strictly correct. However, the data do show that the upper surface corrodes at a more rapid rate than the lower, but the relative rates of corrosion between upper and lower surfaces depend upon the location.

Corrosion Damage to Steel as Measured by Steel Weight Loss:

The steel weight loss data for the panels removed in 1952 are given in Table X. The data for Kure Beach seemed erratic and inconsistent. Additional panels were therefore removed from this site in 1954 (10.7 yr) and

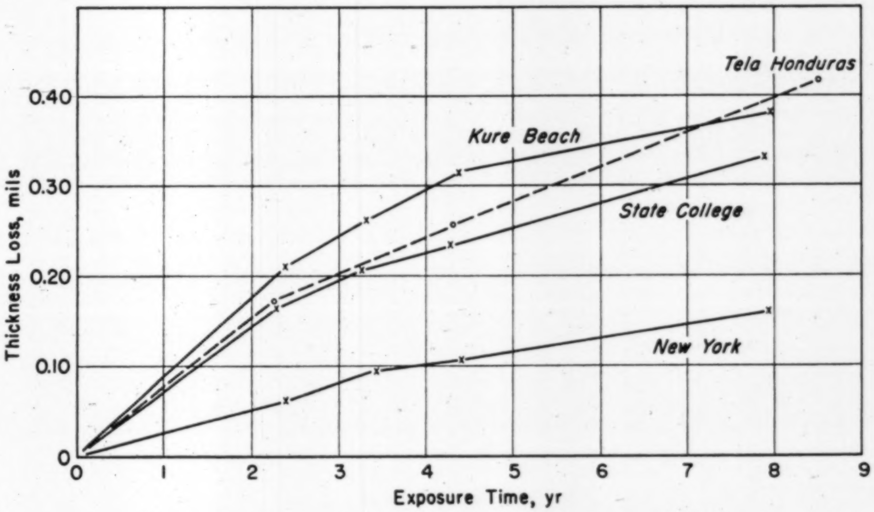


FIG. 1.—Thickness Loss of Lead Coating *versus* Exposure Time.

TABLE X.—STEEL CORROSION FROM WEIGHT LOSS OF STRIPPED PANELS.

Nominal Lead Coating Thickness, in.	New York (8.38 yr)		Kure Beach (8.27 yr)		State College (8.36 yr)		Tela, Honduras (8.40 yr)	
	Panel	Weight Loss, g	Panel	Weight Loss, g	Panel	Weight Loss, g	Panel	Weight Loss, g
BARE STEEL								
None......	No. 613	52.47	No. 615	51.66	No. 614	26.88	Not returned	Not returned
SULFAMATE LEAD ON BARE STEEL								
0.0005.....	No. 13	0.05	No. 15	26.82	No. 18	3.43	No. 4	13.68
0.0010.....	No. 37	0.01	No. 39	0.82	No. 42	0.69	No. 28	2.48
FLUOBORATE LEAD ON BARE STEEL								
0.00008....	No. 776	7.49	No. 773	27.74	No. 774	14.64	No. 777	41.08
0.00025....	No. 61	0.57	No. 63	15.95	No. 66	9.88	No. 59	31.75
0.00050....	No. 85	0.24	No. 87	8.85	No. 91	4.22	No. 81	12.95
0.00075....			No. 123	5.10	No. 126	2.33	No. 112	6.27
0.00100....	No. 145	0.17	No. 147	2.84	No. 150	1.19	No. 143	4.37
SULFAMATE LEAD ON CU-PLATED STEEL								
0.0005.....	No. 253	0.07	No. 255	20.09	No. 258	4.25	No. 249	Not returned
0.0010.....	No. 277	0.10	No. 279	0.01	No. 282	0.00	No. 273	0.53
FLUOBORATE LEAD ON CU-PLATED STEEL								
0.00008....	No. 800	12.36	No. 797	49.00	No. 798	19.85	No. 801	56.65
0.00025....	No. 301	0.34	No. 303	20.26	No. 290	12.35	No. 292	31.35
0.00050....	No. 325	0.22	No. 327	7.57	No. 319	4.28	No. 323	12.89
0.00075....	No. 361	0.21	No. 363	Not returned	No. 366	0.87	No. 352	2.48
0.0010.....			No. 387	3.80	No. 390	0.10	No. 381	0.12

TABLE XI.—STEEL CORROSION FROM TENSILE PROPERTIES OF STRIPPED PANELS.

Thickness, in.	New York (8.38 yr)							Kure Beach (8.27 yr)						
	Panel	Elongation		Yield Strength		Tensile Strength		Panel	Elongation		Yield Strength		Tensile Strength	
		Per Cent	Per Cent Change	Psi	Per Cent Change	Psi	Per Cent Change		Per Cent	Per Cent Change	Psi	Per Cent Change	Psi	Per Cent Change
BARE STEEL														
None........	No. 613	2.0	−92.8	17 600	−61.1	18 500	−65.8	No. 615	5.0	−82.4	26 500	−41.4	32 100	−40.8
SULFAMATE LEAD ON BARE STEEL														
0.00050......	No. 13	10.3	−36.1	42 850	−5.2	49 650	−8.3	No. 15	15.3	−46.3	33 600	−25.7	42 000	−22.4
0.00100......	No. 37	31.3	+9.8	41 150	−9.0	51 600	−4.7	No. 39	29.4	+3.2	44 450	−1.7	51 550	−4.8
FLUOBORATE LEAD ON BARE STEEL														
0.00008......	No. 776	26.6	−6.7	42 550	−12.8	47 900	−11.5	No. 773	13.5	−52.5	32 100	−29.0	39 950	−26.2
0.00025......	No. 61	18.1	−36.0	42 600	−5.8	49 750	−8.1	No. 63	15.0	−47.3	35 700	−21.0	41 200	−23.9
0.00050......	No. 85	19.9	−33.2	42 650	−10.1	48 400	−10.6	No. 87	20.2	−29.1	38 700	−14.4	47 000	−13.2
0.00075......								No. 123	11.9	−41.7	41 300	−8.6	46 000	−15.1
0.00100......	No. 145	31.9	+11.9	42 450	−6.1	51 150	−5.5	No. 147	17.2	−39.6	42 050	−7.0	48 500	−10.4
SULFAMATE LEAD ON CU-PLATED STEEL														
0.00050......	No. 253	30.2	+6.0	44 150	−2.3	51 700	−4.5	No. 255	12.4	−56.4	32 050	−29.1	39 100	−27.8
0.00100......	No. 277	19.6	−31.2	42 650	−5.6	50 250	−7.2	No. 279	28.4	−0.4	44 350	−1.9	52 200	−3.6
FLUOBORATE LEAD ON CU-PLATED STEEL														
0.00008	No. 800	17.7	−38.2	35 600	−21.1	44 450	−17.9	No. 797	Perforated					
0.00025......	No. 301	19.4	−31.9	44 550	−1.4	49 850	−7.9	No. 303	14.5	−49.1	34 450	−23.8	40 700	−24.8
0.00050......	No. 325	30.2	+5.9	44 100	−2.4	52 500	−3.0	No. 327	17.8	−37.6	40 500	−10.4	45 200	−16.7
0.00075......	No. 361	34	+19.3	44 050	−2.5	52 400	−3.2	No. 363	Not returned					
0.0010.......								No. 387	24.6	−13.7	41 950	−7.2	50 050	−7.6

	State College (8.36 yr)							Tela, Honduras (8.40 yr)						
BARE STEEL														
None........	No. 614	12.5	−56.2	34 100	−24.6	40 450	−25.3	Not returned						
SULFAMATE LEAD ON BARE STEEL														
0.0005.......	No. 18	27.5	−3.5	43 000	−4.9	50 800	−6.2	No. 4	13.7	−51.8	36 700	−18.8	43 650	−19.4
0.0010.......	No. 42	18.9	−33.7	45 400	+0.4	51 000	−5.8	No. 28	27.4	−3.9	43 600	−3.5	50 450	−6.8
FLUOBORATE LEAD ON BARE STEEL														
0.00008......	No. 774	22.3	−21.7	36 450	−19.4	45 300	−16.4	No. 777	4.3	−84.8	24 600	−45.6	24 850	−54.2
0.00025......	No. 66	27.8	−2.4	39 850	−11.8	47 200	−12.8	No. 59	8.4	−70.5	30 000	−33.7	35 350	−16.3
0.00050......	No. 91	30.7	+7.7	44 200	−2.2	50 700	−6.4	No. 81	15.3	−46.3	38 250	−15.4	44 150	−18.5
0.00075......	No. 126	20.0	−29.8	44 150	−2.3	49 650	−8.3	No. 112	18.2	−36.2	40 150	−11.2	48 200	−11.0
0.00100......	No. 150	30.3	+6.3	44 350	−1.9	51 900	−4.2	No. 143	13.9	−51.2	43 500	−3.8	47 800	−11.7
SULFAMATE LEAD ON CU-PLATED STEEL														
0.0005.......	No. 258	19.6	−31.3	40 150	−11.2	46 250	−14.6	No. 249	Not returned					
0.0010.......	No. 282	26.1	−8.4	45 100	−0.2	52 150	−3.7	No. 273	18.2	−36.1	45 300	+0.2	49 450	−8.7
FLUOBORATE LEAD ON CU-PLATED STEEL														
0.00008......	No. 798	12.4	−56.5	34 100	−24.6	39 300	−27.4	No. 801	Perforated					
0.00025......	No. 290	20.9	−26.7	37 950	−16.1	46 000	−15.1	No. 292	5.9	−79.3	29 000	−35.8	29 950	−44.7
0.00050......	No. 319	18.4	−35.4	40 850	−9.6	46 250	−14.6	No. 323	13.0	−54.3	37 800	−16.4	42 400	−21.7
0.00075......	No. 366	17.4	−38.9	44 500	−1.5	50 100	−7.5	No. 352	22.9	−19.6	44 050	−2.5	51 050	−5.7
0.00100......	No. 390	19.6	−31.2	44 800	−0.9	51 800	−4.3	No. 381	15.3	−46.3	45 350	+0.3	50 800	−6.2

NOTE.

Tensile properties are calculated on the basis of original steel thickness.

Values are the average of data from two standard sheet tension specimens from each panel.

Original properties from lead-coated, stored, and stripped panels:

Elongation in 2 in.	28.5 per cent
Yield strength	45 200 psi
Ultimate tensile strength	54 150 psi

steel weight loss determined. These data are given in Table XII and, being more consistent than the Kure Beach data in Table X, are used for the Kure Beach curves in Figs. 2 and 3. The weight losses averaged for given coating thicknesses without regard to undercoating or type of plating bath are plotted in Fig. 2. The effect of a copper flash (0.015 mil) on steel as a base for electroplated lead is shown in Fig. 3. These data in general substantiate the results of visual inspection, and the generalizations given in the 1949 report (p. 224) are still correct with the possible exception that the Tela atmosphere now seems as severe or more so than that at Kure Beach. It would appear from the lead weight loss (Fig. 1) and a comparison of the steel weight loss data in Table VIII of the 1949 report and Table IV of this report that the corrosion for Tela has continued at a constant rate since 1946, whereas that at Kure Beach has decreased.

The effect of a copper flash, as shown in Fig. 2 of the 1949 report, was to accelerate corrosion for thin deposits and retard corrosion for the heavier deposits. Four years later, as shown in Fig. 3 of this report, the same general effect is still evident.

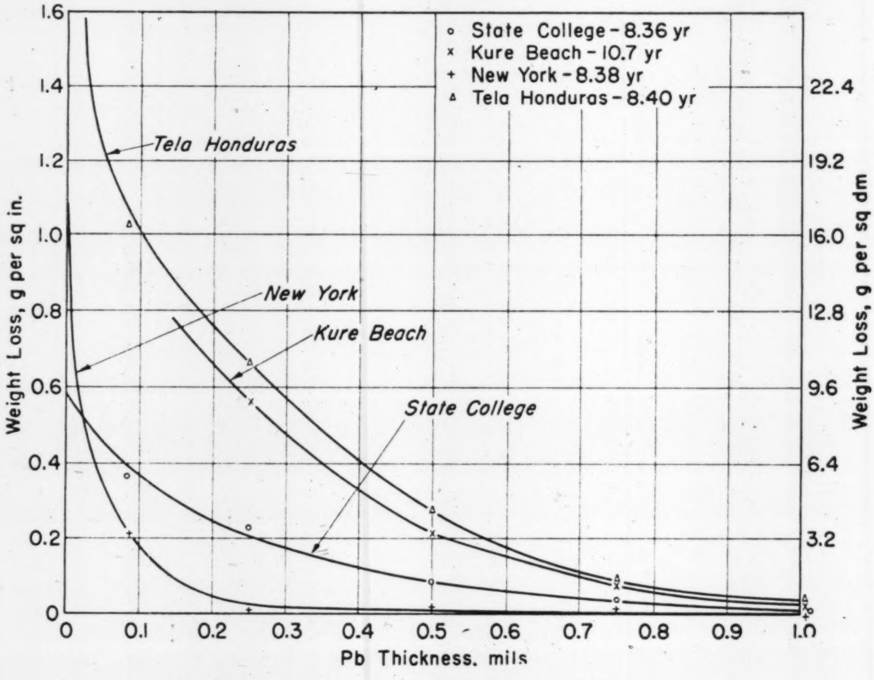


FIG. 2.—Weight Loss of Steel *versus* Thickness of Lead Coating.

Corrosion Damage to Steel as Measured by Change in Tensile Strength:

The results for elongation, yield strength, and tensile strength determinations are given in Table XI. While such measurements are less precise than those for weight loss, the results confirm the conclusions previously stated, primarily in regard to corrosivity of different atmospheres, effect of thickness, and effect of the copper flash.

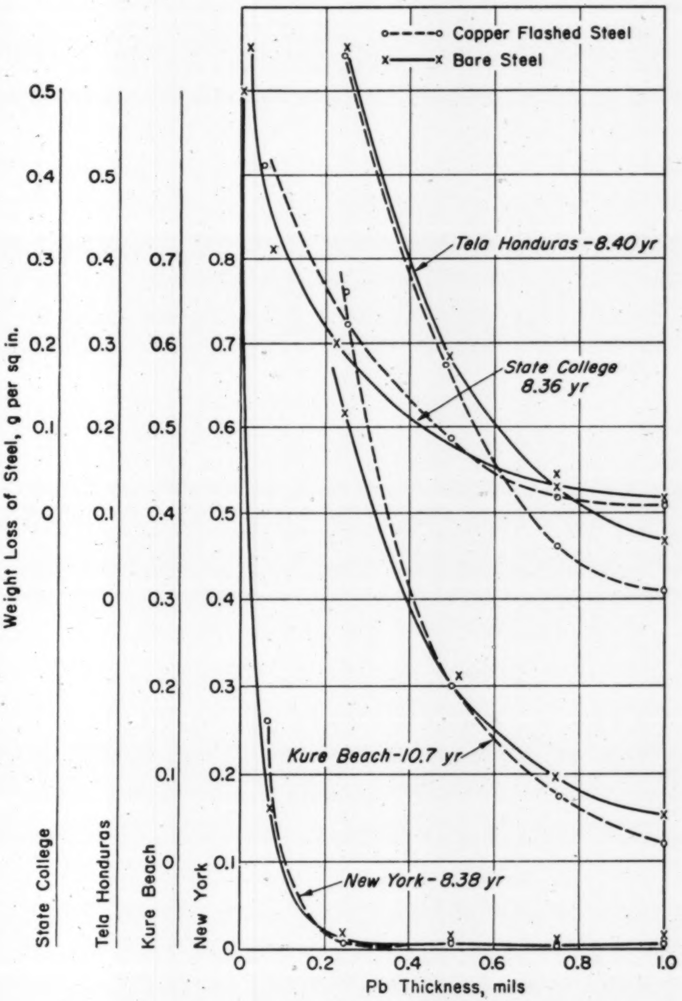


FIG. 3.—Weight Loss of Steel *versus* Thickness of Lead Coating.

Protective Film at New York:

It is obvious from all of the data—lead and steel weight loss as well as visual inspection—that the atmosphere at New York forms a film which protects the lead coating and thereby the lead-coated steel. It was also observed in recent years that the panels with thin lead deposits (0.08 and 0.25 mil) at

TABLE XIII.—RELATIVE CORROSION OF ELECTROPLATED LEAD ON UPPER AND UNDER SURFACES.

	Loss in Deposit Thickness, mil	
	Upper Surface	Under Surface
New York, N. Y.	0.40; 0.50	−0.04; 0.04
Kure Beach, N. C.	0.56; 0.65	0.32; 0.25
State College, Pa.	0.78; 0.80	0.09; 0.04

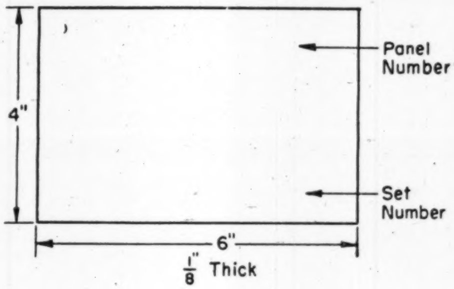
New York, while being completely covered with a rust film, apparently were being protected by this film. Panels were therefore removed and the films inspected for chemical and structural constitution. For both the 0.08- and 0.25-mil original lead thicknesses, the amount of iron predominated over that of lead. There was no detectable lead metal remaining on the 0.08-mil panels, and the film on these consisted mostly of $\alpha Fe_2O_3 \cdot H_2O$. The structure of the film on the 0.25-mil panels was very complex and contained $PbSO_4$, βFe_2O_3, some $PbO \cdot PbSO_4$, and several unidentified compounds. It did not contain $PbCO_3$, $Pb_2(OH)_2CO_3$, γFe_2O_3, FeO, PbOCl, PbO_2, PbO, PbS, CuS, or $CuFeS_2$. Copper metal was still present on the 0.25-mil panels but not on the 0.08-mil panels.

Respectfully submitted on behalf of the subcommittee,

W. L. PINNER,
Chairman.

APPENDIX

A. Detail on Test Panels SAE 950 Steel, Bumper Stock, Finish—5 microinch rms:



B. Steel Cleaner:

Proprietary cleaner—"F." 8 oz per gal, 180 F, anodic 12 v, 1 min.

C. Copper Cleaner:

Proprietary cleaner—"G." 8 oz per gal, 180 F, cathodic 12 v, $\frac{3}{4}$ to 1 min.

D. Cyanide Copper Strike:

Copper (Cu)	2.4 oz per gal
Free cyanide (NaCN)	1.0 oz per gal
Rochelle salt	3.0 oz per gal
Carbonate (Na_2CO_3)	4.6 oz per gal
Temperature	110 F
Current	40 amp per rack

Thickness, in.	Time, min
0.00005	2½
0.0002	9½
0.0001	5

E. Acid Copper, Thiourea Type:

Copper sulfate ($CuSO_4 \cdot 5H_2O$)	27 oz per gal
Sulfuric acid (H_2SO_4)	7.8 oz per gal

Addition agents were present to improve deposits.

Air agitation was used.

Temperature	120 F
Current	75 amp per rack

Thickness, in.	Time, min.
0.00095	55
0.0008	50
0.00045	25
0.0003	20

F. Nickel Strike:

Nickel sulfate ($NiSO_4 \cdot 7H_2O$)	18 oz per gal
Nickel chloride ($NiCl_2 \cdot 6H_2O$)	18 oz per gal
Hydrochloric acid (HCl)	10 per cent by volume
Temperature	70 F
Time	1 min
Current	100 amp per rack
Voltage	5 v

G. Watt's Nickel:

Nickel (Ni)	6.6 oz per gal
Chloride (Cl)	1.8 oz per gal
Boric acid (H_3BO_3)	4.8 oz per gal
pH (electrometric)	3.5
Temperature	130 F
Current	90 amp per rack

Thickness, in.	Time, min
0.001	25
0.0014	40

H. Bright Nickel Process "H":[1]

Nickel (Ni)	10.5 oz per gal
Chloride (Cl)	2.6 oz per gal
Boric acid (H_3BO_3)	5.0 oz per gal
Brightener 3	0.4 oz per gal
Nonpitter 22	0.5 gal per 100 gal
Brightener 1 RL	0.15 gal per 100 gal
pH (electrometric)	3.5
Temperature	140 F
Current	70 amp per rack

Thickness, in.	Time, min
0.00015	48
0.0005	16
0.001	32

Cathode rod agitation was used.

I. Chromium:

Chromic acid (CrO_3)	33.3 oz per gal
Sulfate (SO_4)	0.33 oz per gal
Ratio	100:1
Temperature	115 F
Time	2 min
Current	300 amp per rack

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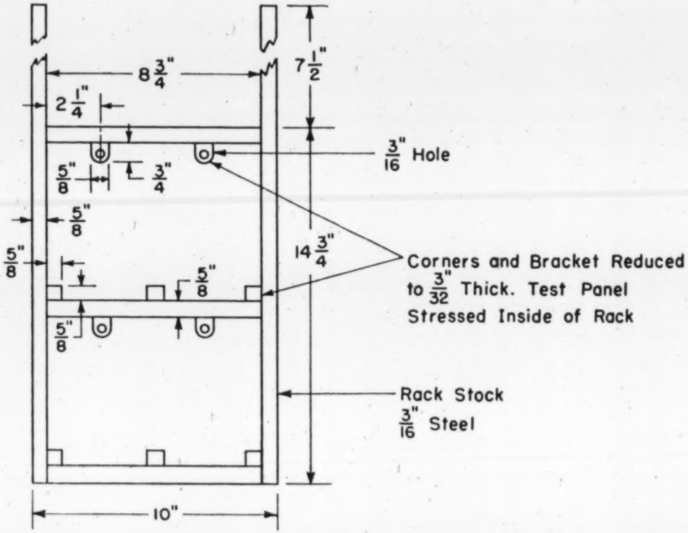
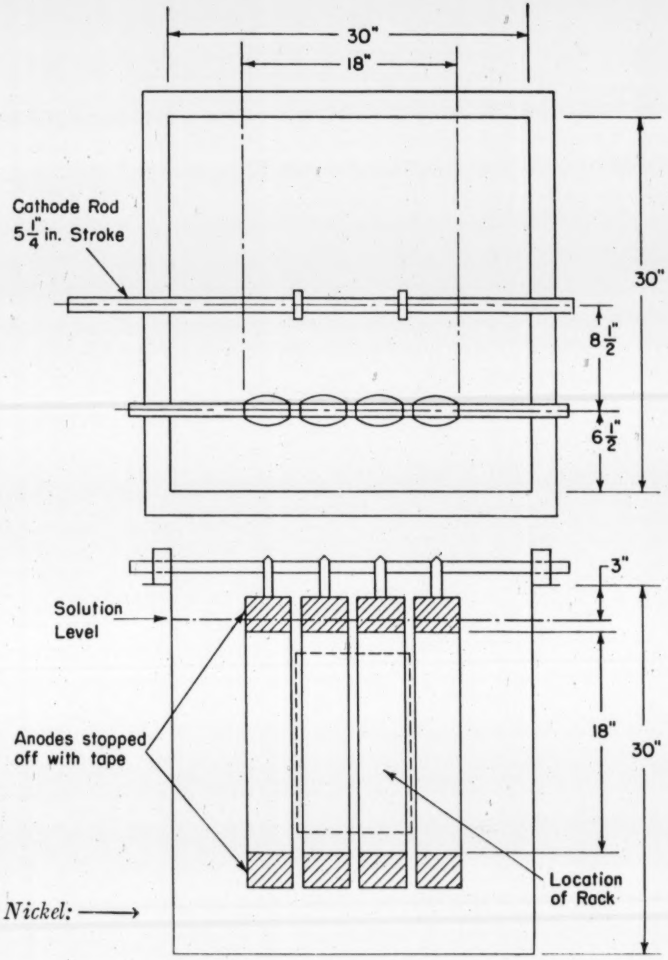
[1] Purified and adjusted according to vendor's recommendation.

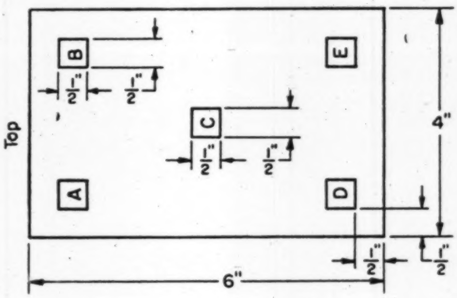
J. Detail of Plating Rack:


8 3/4"
7 1/2"
2 1/4"
3/16" Hole
5/8"
3/4"
5/8"
5/8"
14 3/4"
Corners and Bracket Reduced to 3/32" Thick. Test Panel Stressed Inside of Rack
5/8"
5/8"
Rack Stock 3/16" Steel
10"

K. Detail of Plating Tank for Bright and Watt's Nickel: ⟶


30"
18"
Cathode Rod 5 1/4 in. Stroke
30"
8 1/2"
6 1/2"
3"
Solution Level
18"
30"
Anodes stopped off with tape
Location of Rack

L. Detail of Mask Used in Locating Panel Positions for Thickness Determinations:



M. Standardization of Plate Thickness of Bright Nickel—Process "H":

Numbers refer to panel position on rack (see section J above).

Capital letters refer to position on panel (see section L above).

The thickness is given in mils and is an average of three magnegage readings for each location.

Series AA:

Six Ni anodes used, all on the face side. 65 amp per rack. 40 min.

	Thickness, mils				
	A	B	C	D	E
No. 1..........	1.32	1.21	1.17	1.40	1.22
No. 2..........	1.19	1.39	1.17	1.26	1.48
No. 3..........	1.35	1.21	1.28	1.81	1.75
No. 4..........	1.19	1.52	1.21	1.64	1.78

Plate too thick; variation too great.

Series BB:

Four Ni anodes used, all on the face side. 65 amp per rack. 32 min.

	Thickness, mils				
	A	B	C	D	E
No. 1..........	0.81	0.79	0.78	0.94	0.83
No. 2..........	0.88	0.86	0.87	0.93	0.96
No. 3..........	1.05	1.00	1.04	1.40	1.20
No. 4..........	1.03	1.17	1.14	1.43	1.55

Microscopic thickness at C:

No. 1..................	**0.77 mils**
No. 2..................	**0.86 mils**
No. 3..................	**1.20 mils rechecked**
No. 4..................	**1.08 mils rechecked**

The microscopic test is in close agreement with the magnegage. Microscopic value of sample No. 3 must be in error due to improper mounting.

Series CC:

Four anodes as in Series BB but stopped off at top and bottom with tape to match panel area. Anode to cathode rod spacing 8½ in. center to center. 65 amp per rack. 32 min.

	Thickness, mils				
	A	B	C	D	E
No. 1..........	0.78	0.69	0.80	1.00	0.86
No. 2..........	0.70	0.83	0.84	0.84	0.96
No. 3..........	1.00	0.87	0.85	1.12	0.96
No. 4..........	0.84	1.01	0.90	1.05	1.10

Fairly uniform but over-all thickness too thin in center of panel.

Series DD:

Anodes same as Series CC but different current density and time. 70 amp per rack. 35 min.

	Thickness, mils				
	A	B	C	D	E
No. 1..........	1.22	1.14	1.17	1.22	1.15
No. 2..........	1.10	1.25	1.14	1.11	1.22
No. 3..........	1.08	1.01	1.08	1.33	1.28
No. 4..........	1.01	1.15	1.03	1.15	1.32

More uniform but a little too heavy in center of panel.

Series EE:

Anodes same as Series CC. Less time than Series DD. 70 amp per rack. 32 min.

	Thickness, mils				
	A	B	C	D	E
No. 1..........	1.05	0.96	1.0	1.05	0.93
No. 2..........	0.93	1.01	0.98	0.90	1.01
No. 3..........	0.92	0.84	0.93	1.11	0.95
No. 4..........	0.83	1.04	0.94	1.01	1.08

Microscopic thickness readings at C:

No. 1	1.0 mil
No. 2	0.99 mil
No. 3	0.98 mil
No. 4	0.98 mil

The microscopic readings indicate good agreement, and these conditions were chosen as standard for the deposition of bright nickel for 0.001-in. thickness.

N. Standardization of Chromium:

300 amp per rack. 3-min. plating time. Thickness determined by standard drop test and given in mils.

	Thickness, mils				
	A	B	C	D	E
No. 1	0.017	0.023	0.017	0.034	0.030
No. 2	0.017	0.026	0.022	0.026	0.038
No. 3	0.026	0.018	0.022	0.046	0.035
No. 4	0.017	0.020	0.022	0.045	0.041

The chromium thickness is a little more than desired. The time was reduced to 2 min. for all plates.

O. Cyanide Copper Strike:

9½ min. 40 amp per rack.

	Thickness, mils		
	A	C	E
No. 1	0.20	0.18	0.20
No. 2	0.25	0.20	0.20
No. 3	0.22	0.18	0.21
No. 4	0.21	0.19	0.20

Since this was good agreement, a proportionate fraction of the above time was used to give the thinner deposits, which were too thin to measure accurately.

P. Standardization of Watt's Nickel:

The magnegage standard curve did not hold for buffed Watt's nickel, and a new one was drawn based on microscopic thickness determinations.

Panel and Location	Microscopic Thickness, mils	Magnegage Reading
No. 1C	1.45	103
No. 2C	1.50	112
No. 3C	1.48	108
No. 4C	1.68	113

The curve drawn, based on the above data, was used for determining the thickness of Watt's nickel on panels for lots Nos. 6 and 7.

Q. Standardization of Acid Copper:

90 amp per rack. 25 min.

	Thickness, mils				
	A	B	C	D	E
No. 1	0.59	0.50	0.48	0.62	0.48
No. 2	0.50	0.60	0.49	0.45	0.60
No. 3	0.63	0.46	0.54	0.87	0.74
No. 4	0.49	0.63	0.55	0.71	0.92

Microscopic thickness at C:

No. 1	0.48 mil
No. 2	0.47 mil
No. 3	0.48 mil
No. 4	0.52 mil

Based on these values, the standard curve with the magnegage was valid and used for determining the acid and cyanide copper thickness.

REPORT OF COMMITTEE B-9

ON

METAL POWDERS AND METAL POWDER PRODUCTS*

Committee B-9 on Metal Powder and Metal Powder Products held one meeting during the year: in Chicago, Ill. on February 16, 1955.

During the year, F. V. Lenel resigned the chairmanship of Committee B-9 and the Advisory Committee appointed J. L. Bonanno, Vice-Chairman, to serve out Mr. Lenel's unexpired term. H. R. Biehl was appointed Vice-Chairman for the unexpired term and F. V. Lenel was appointed to the Advisory Committee.

NEW TENTATIVE

The committee recommends that the Specifications for Copper Infiltrated Iron Parts be accepted for publication as tentative as appended hereto.[1]

REVISION OF TENTATIVE

The committee recommends that the Tentative Specifications for Metal Powder Sintered Bearings (Oil Impregnated) (**B 202 - 51 T**)[2] be revised as appended hereto.[3]

ADOPTION OF TENTATIVE AS STANDARD WITHOUT REVISION

The committee recommends that the Tentative Definitions of Terms Used in Powder Metallurgy (**B 243 - 49 T**)[2] be approved for reference to letter ballot of the Society for adoption as standard without change.

REAPPROVAL OF STANDARDS

The committee recommends that the following methods be reaffirmed as standard without change:

Standard Method of:

Test for Apparent Density of Metal Powders (**B 212 - 48**),

Test for Flow Rate of Metal Powders (**B 213 - 48**),

Test for Sieve Analysis of Granular Metal Powders (**B 214 - 48**), and

Sampling Finished Lots of Metal Powders (**B 215 - 48**).

TENTATIVE CONTINUED WITHOUT REVISION

The committee recomends that the Specifications for Sintered Metal Powder Structural Parts from Brass (**B 282 - 53 T**) be continued as tentative in view of pending changes.

The recommendations in this report have been submitted to letter ballot of the committee, the results of which will be reported at the Annual Meeting.[4]

ADVISORY COMMITTEE ACTIVITIES

The Advisory Committee held three meetings during the year to act on various committee administrative matters. A change was made in the chairmanship and vice-chairmanship of Committee B-9 precipitated by the resignation of F. V. Lenel as chairman. C. H. Toensing was appointed to represent Committee B-9 on Committee E-1 on Methods of Testing. Due to the resignation of R. A. Canning, E. W. Engle was appointed chairman of Subcommittee III-C.

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* Presented at the Fifty-eighth Annual Meeting of the Society, June 26–July 1, 1955.

[1] The new tentative appears in the 1955 Book of ASTM Standards, Part 2.

[2] 1952 Book of ASTM Standards, Part 2.

[3] The revised tentative appears in the 1955 Book of ASTM Standards, Part 2.

[4] The letter ballot vote on these recommendations was favorable; the results of the vote are on record at ASTM Headquarters.

A. S. Doty was appointed to the chairmanship of a newly formed Subcommittee III-E on Machinable Heavy Metals.

ACTIVITIES OF SUBCOMMITTEES

Subcommittee I on Nomenclature and Technical Data (F. N. Rhines, chairman) held two meetings during the year. This committee unanimously recommended that the Tentative Definitions of Terms Used in Powder Metallurgy (B 243 - 49 T) be adopted as standard without change; also, that the term "sintering" be tabled until such a time as usage of this term would justify its use as a term to denote a product of powder metallurgy. One task group has the assignment of gathering data on the properties of iron-copper alloys made under the restrictions of Specification B 222 - 52, and another task group, under the leadership of H. R. Biehl, has instituted a survey to determine the variation in the "*K*"-factor for bearings manufactured under the restrictions of Specifications B 202 - 5T.

Subcommittee II on Metal Powders (J. J. Cordiano, chairman):

Section A on Base Metal Powders (J. J. Cordiano, chairman).—By unanimous vote this section recommended the reaffirmation as standard of methods B 212 - 48, B 213 - 48, B 214 - 48, and B 215 - 48.

Cooperative compressibility tests are continuing in an effort to develop a basis for a tentative standard. A draft of a test procedure for green strength of compacted metal powder specimens is being submitted to subcommittee letter ballot. The hydrogen loss test methods and methods of chemical analysis of metal powders have been reviewed with a task group of Committee E-3 on Chemical Analysis of Metals, and these methods are being further studied by a joint task group of Committees B-9 and E-3.

Section B on Refractory Metal Powders (W. H. Bleecker, chairman) is working on the problem of determining particle size distribution in the low micron range of refractory metal powders, and in view of the difficulty encountered it plans to seek help on this problem from the ASTM Administrative Committee on Research.

Subcommittee III on Metal Powder Products (R. P. Koehring, chairman):

Section A on Bearings (S. A. Sesny, chairman).—The revision of Specification B 202 - 51 T was completed and unanimously approved by this section. A task group investigated the "*K*"-factor used in the radial crushing strength test method for plain bearings and recommended further work on this subject be carried out by Subcommittee I.

Section B on Structural Parts (P. J. Shipe, chairman) prepared the Specifications for Copper Infiltrated Iron Parts referred to earlier in this report for publication as tentative. This section is working on a proposed tentative specification for sintered iron structural parts. It has appointed task groups to prepare the first draft of specifications covering high density iron parts and to study the formulation of specifications for structural parts looking toward improving the quality and increasing the usefulness of such specifications.

Section C on Cemented Carbides (E. W. Engle, chairman).—A task group is preparing data covering physical properties of cemented carbides. A method for determining density has been prepared and will be submitted to the section for approval. An effort is being made to increase the consumer representation on this section.

Section E on Machinable Heavy Metals (A. S. Doty, chairman).—This newly formed section is planning to work on specifications covering standardization, chemical composition, physical and mechanical properties of machinable heavy metals; also, to investigate the possibilities of specifications applicable to radiation shielding applications for this class of material.

This report has been submitted to letter ballot of the committee, which consists of 66 members; 54 members returned their ballots, of whom 49 have voted affirmatively and 0 negatively.

Respectfully submitted on behalf of the committee,

J. L. BONANNO,
Chairman.

C. G. JOHNSON,
Secretary.

REPORT OF ADVISORY COMMITTEE

ON

CORROSION*

The Advisory Committee on Corrosion held three meetings during the past year: on June 17, 1954, at the Annual Meeting in Chicago; on December 31, 1954, at the International Nickel Co. offices in New York; and on February 1, 1955, during Committee Week.

Personnel

Committee C-22 on Porcelain Enamel, Committee A-3 on Cast Iron, and Committee A-7 on Malleable-Iron Castings have appointed members to the Advisory Committee: W. N. Harrison and B. J. Sweo, H. W. Stuart and J. T. McKenzie, and W. A. Kennedy and J. H. Lansing, respectively. Representation from Committee D-14 has been changed from Gerald Reinsmith and R. C. Platow to R. F. Blomquist and D. A. George. R. J. McKay has retired and has been replaced by R. B. Saltonstall as the representative of Committee B-8.

H. A. Pray was reappointed as member-at-large for the three-year term from June, 1954, to June, 1957. C. P. Larrabee has been appointed a member-at-large for the three-year term expiring in June, 1958.

A. W. Tracy was appointed to fill the unexpired term of Sam Tour on the Inter-Society Corrosion Committee, term expiring in September, 1954. He was reappointed for a full term of six years expiring in September, 1960.

The election of officers for the ensuing term of two years resulted in the selection of the following:

Chairman, Jerome Strauss.

First Vice-Chairman, K. G. Compton.

Second Vice-Chairman, W. H. Finkeldey.

Committee C-19 Exposure Program

The only new exposure program during the past year which reached the point of actual exposure of specimens was that of Committee C-19 on Structural Sandwich Constructions. Committee C-19 through its Subcommittee III on Permanence, Durability, and Simulated Service has exposed at Kure Beach, N. C., and at State College, Pa., a total of 80 panels, each 15 in. square, which are to be used for determining the effect of atmospheric exposure on edgewise compression and flatwise flexure properties. In addition there will be visual inspection of the various cores and facing materials.

This is the first committee on nonmetallic materials to take advantage of the facilities that have been developed (with the exception of a small program by Committee D-1 on Paint, Varnish, Lacquer, and Related Products, the purpose of which was to evaluate the dirt-retentive properties of various paint formulas).

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* Presented at the Fifty-eighth Annual Meeting of the Society, June 26–July 1, 1955.

TEST SITE CHANGES

New York, N. Y.:

The test site located on the 16th floor penthouse roof of the Port of New York Authority Building has been subjected to small oil droplets from helicopters using the nearby heliport. There has been some discussion as to whether the site should be moved to some other nearby location such as Kearney, N. J. With this possibility in mind, Subcommittee VII of Committee B-3 on Corrosion of Non-Ferrous Metals and Alloys has been asked to evaluate the proposed site at Kearney. A final decision on whether the site should be transferred will be made by June, 1956.

Mohave Desert Test Site:

Committee B-6 on Die-Cast Metals and Alloys plans to develop the necessary liaison so that a number of specimens can be exposed at the Naval installation at Inyokern (China Lake), Calif. The Advisory Committee looks with favor upon this collaboration between Committee B-6 and the Navy but is not considering using the Mohave site on the scale contemplated for the principal sites already established.

Sandia, N. M., Test Site:

The Sandia Corp., Sandia Base, Albuquerque, N. M., offered part of their large exposure site at that location to the ASTM for the purpose of exposing ASTM specimens. Although there is no immediate demand for a test site having this type of environment, the Advisory Committee accepted this generous offer of space from the Sandia Corp. with the thought that future needs of the Society could conceivably include a location in this area of the country.

Key West, Fla.:

As a result of data from tests extending over more than 10 yr at Key West, it was agreed that the classification of this site should be changed from "Marine" to "Rural (Marine)." A more detailed report on the reasons for this change will be included in the ASTM BULLETIN.

ENGINEERING FOUNDATION CORROSION RESEARCH COUNCIL

The Advisory Committee on Corrosion considered the request of the Engineering Foundation to cosponsor a "Corrosion Research Council," a group which would have as its scope the stimulation of fundamental research in the field of corrosion. The Committee recommended to the ASTM Board of Directors that direct sponsorship would not be practical but that it was sympathetic with the objects of the Corrosion Research Council and that it would be desirable to maintain liaison with this group. The Chairman is serving as a member of the Steering Group and will keep the ASTM posted. Current plans of the Council's Steering Committee call for raising $200,000 to be spent eventually at a rate of $100,000 a year. By the time the initial sum is spent, the results obtained will illustrate the extent to which this research program can be continued.

COOPERATION WITH CANADA

On the recommendation of the Advisory Committee on Corrosion, Subcommittee VII of Committee B-3 on Corrosion of Non-Ferrous Metals and Alloys made available to E. V. Gibbons, Chairman of Subcommittee C of the Committee on Corrosion Research and Prevention of the National Research Council of Canada, seven sets of calibration specimens to be used in calibrating the recently established Canadian test sites. These calibration specimens are of the same lots of zinc and iron as those used for the ASTM test sites. The use of the same materials at both the U. S.

and Canadian test sites will help in evaluating the relative corrosivity of all the sites in both countries.

CENTRALIZATION OF CORROSION ACTIVITIES

One of the items discussed at both the June and December, 1954, meetings was the suggestion that the various subcommittees or task groups of any of the technical committees directly concerned with corrosion or corrosion testing be incorporated into one central committee, the thought being that since multiple representation is usually involved such an arrangement would facilitate meeting attendance.

It was the consensus of the Advisory Committee that consolidation of all the Society's corrosion activities would not be feasible. As a possible saving of time on the part of the committee members, the Secretary will keep the members posted as to the time and date an inspection group plans to visit a particular site so that where practical a single group can attend to a number of test programs.

FINANCIAL STATUS

Facilities are now available at all of the test sites with the exception of Phoenix, Ariz., and Sandia, N. M. Although there will be continuing expenses for additional facilities and maintenance items such as painting, replacement of specimen racks (a number of galvanized racks have been in use for more than 10 yr in a marine environment), etc., it is apparent that the $44,300 spent in the 6 yr since the Test Site Fund was established has gone far toward providing the necessary sites and facilities as required by the technical committees of the Society. There is a cash balance available of $63,000 and about $5000 still outstanding in the form of pledges.

1956 CORROSION EXHIBIT

In view of the various new exposure programs established since 1952 and as a result of the interest shown in the modest corrosion exhibit held that year, it was agreed that a Society-wide corrosion exhibit should be held at the 1956 Annual Meeting and Exhibit to be held in Atlantic City, N. J., during the week of June 17. At the request of the ASTM Southern California District Council, it was also agreed that the exhibit should be displayed at the Second Pacific Area National Meeting to be held the week of September 16, 1956, in Los Angeles.

Respectfully submitted on behalf of the committee,

F. L. LAQUE,
Chairman.

J. S. PETTIBONE,
Secretary.

REPORT OF JOINT COMMITTEE
ON
EFFECT OF TEMPERATURE ON THE PROPERTIES OF METALS[*]

Meetings:

Meetings of the Joint ASTM-ASME Committee on the Effect of Temperature on the Properties of Metals, its panels, and subcommittees were held during the past year in connection with the Annual Meetings of the ASTM in Chicago, Ill., June 14 to 18, 1954, and of the ASME in New York, N. Y., November 28 to December 3, 1954. All the panels, excepting the Test Methods Panel, met at both annual meetings.

Technical Sessions and Papers:

The following papers were presented at sessions sponsored by the joint committee:

Annual Meeting of the ASTM:

"The Strength of Carbon Steels for Elevated Temperature Applications," by R. F. Miller.[1]

"Statistical Evaluation of the Creep-Rupture Properties of Four Heat-Resistant Alloys in Sheet Form," by A. I. Rush and J. W. Freeman.[2]

"Elevated Temperature Fatigue Properties of Several High-Temperature Sheet Materials," by D. C. Goldberg and J. J. Lombardo.[3]

"Thermal Shock Testing Procedure," by A. W. F. Green, K. Lampson, and T. Tsareff.

Annual Meeting of the ASME:

"Carbon-Molybdenum Steel Steam Pipe after 100,000 hr of Service," by R. J. Sinnott, I. A. Rohrig, J. W. Freeman, and A. I. Rush.

"Investigation into Blade-Root Fixings of High-Temperature Steels," by W. Siegfried.

"Factors Influencing the Notch Fatigue Strength of N-155 Alloy at Elevated Temperatures," by W. S. Hyler and W. F. Simmons.

"Factors Influencing the Notch-Rupture Strength of Heat-Resistant Alloys at Elevated Temperatures," by R. L. Carlson, R. J. MacDonald, and W. F. Simmons.

"Properties of Cast Iron at Elevated Temperatures," by J. R. Kattus.

Eight papers were presented in a Symposium on Effect of Cyclic Heating and Stressing on Metals at Elevated Temperatures in two sessions at the ASTM Annual Meeting. These have been published in a separate publication as *ASTM STP No. 165*.

Membership:

The committee records with sorrow the death of H. Weisberg, a member of long standing who was also a member of the Edison Electric Inst.'s Prime Movers Committee.

Finances:

The committee is grateful for the grant of $500.00 from the Engineering Foundation during the past year. Its unexpended balance as of the end of April was $45,067.18.

Appropriations:

No new contracts were entered into by the committee. The following requests from panels for appropriations were approved:

Project DP-6 on Data on Weldments..	$100.00
DP-11 on Continuous Collection of Data..............	500.00
LT-1 on Publication of Low Temperature Symposium...	3500.00

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[*] Presented at the Fifty-eighth Annual Meeting of the Society, June 26–July 1, 1955.

[1] *Proceedings*, Am. Soc. Testing Mats., Vol. 54, p. 964 (1954).

[2] *Proceedings*, Am. Soc. Testing Mats., Vol. 54, p. 1098 (1954).

[3] *Proceedings*, Am. Soc. Testing Mats., Vol. 54, p. 325 (1954).

ACTIVITIES OF PANELS

Aviation Panel (Leo Schapiro, chairman):

Work under Project AP-1A was submitted as a complete report and presented in the paper "Statistical Evaluation of the Creep-Rupture Properties of Four Heat-Resistant Alloys in Sheet Form," by A. I. Rush and J. W. Freeman.[2]

Project AP-2 has been completed with the presentation of two reports in the form of papers: "Elevated Temperature Fatigue Properties of Several High-Temperature Sheet Materials," by D. C. Goldberg and J. J. Lombardo[3] and "Thermal Shock Testing Procedure," by A. W. F. Green, K. Lampson, and T. Tsareff.

The collection of data on the effect of temperature on the mechanical properties of titanium and titanium alloys has been organized as Project AP-3 under the chairmanship of J. W. Freeman.

Data and Publications Panel (George V. Smith, chairman):

Projects DP-3 and DP-4 have been completed with the publication of *ASTM STP No. 151,* Report on the Elevated-Temperature Properties of Chromium-Molybdenum Steels, and *ASTM STP No. 160,* Report on the Elevated-Temperature Properties of Selected Super-Strength Alloys.

Data collected on aluminum and magnesium alloys under Project DP-9 are being organized for submission in a form suitable for publication. Progress is being made under Project DP-10 toward the collection of data on the physical properties of metals as affected by temperature.

In order to keep information on elevated temperature properties up to date, a Project DP-11 has been organized to devise a form for gathering current data on elevated temperature testing and to make it available as it develops.

Gas Turbine Panel (C. T. Evans, chairman):

Project GTP-1 was completed with the presentation of the report by W. S. Hyler and W. F. Simmons at the 1954 Annual Meeting of the ASME: "Factors Influencing the Notch-Fatigue Strength of N-155 Alloy at Elevated Temperatures."

A study of the oil ash corrosion problem is being undertaken by Project GTP-2 under the chairmanship of C. F. Kottcamp, and Project GTP-5 is undertaking a study of thermal shock under the chairmanship of W. W. Dyrkacz.

General Research Panel (A. J. Herzig, chairman):

A Symposium on Basic Effects of Environment on the Strength, Scaling, and Embrittlement of Metals at Elevated Temperatures[5] was presented during ASTM Committee Week, January 31–February 4, 1955, in Cincinnati, Ohio, with V. N. Krivobok as chairman of the meeting. During the current Annual Meeting, a Symposium on Metallic Materials for Service above 1600 F is being conducted.[6]

The panel has not been able to select a suitable project to be supported by its proposed $7000, two-year fellowship.

Low Temperature Panel (Irving Roberts, chairman):

The panel concluded that the available data on properties of steels at low temperatures are insufficient to warrant a definite conclusion on the degree of impact strength necessary for safety of pressure equipment in low-temperature service and that the limited data available indicate that present code requirements of 15 ft-lb may be reasonable.

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[5] Issued as separate publication *ASTM STP No. 171.*

[6] Issued as separate publication *ASTM STP No. 174.*

A small committee was appointed to work with the Data and Publications Panel in gathering information concerning the physical, as differentiated from the mechanical, properties of metals as they are affected by temperature.

Petroleum and Chemical Panel (*C. L. Clark, chairman*):

Project CP-8 has been completed with the presentation at the 1954 ASTM Annual Meeting of a paper on "The Strength of Carbon Steels for Elevated Temperature Applications," by R. F. Miller.[1] Further work in connection with Project 10, High-Temperature Strength of Welded Joints, comprising short-time tension tests at 200, 400, and 600 F, was planned. Work on Project 10 at the present time is being confined to 1-in. thick, hot-rolled plate of A 201 and A 212, Grade B, automatically and manually welded with several grades of wire. This plate material is the same as that being studied by the Steam Power Panel under their Project SP-4. Testing temperature range extends up to 1000 F.

Work under Project 6 on Graphitization in the Petroleum Industry is at a standstill, but the chairman of the project is keeping in touch with work on the subject being conducted by a task group of the American Petroleum Inst. at Battelle Memorial Inst.

Steam Power Panel (*P. M. Brister, chairman*):

Review of the available information on the subject of Steam and Air Oxidation of Low Alloy Ferritic Steels to 1100 F, obtained under Project SP-1, has been completed and is being prepared for presentation shortly.

A progress report on Project SP-2 (Elevated-Temperature Properties of Cast Iron) was presented by the Southern Research Inst. at the 1954 Annual Meeting of the ASME.

Short-time elevated-temperature tests have been run on both SA-212B plate steels. Creep tests are under way, and rupture tests remain to be started under Project SP-4.

Under Project SP-5, which has taken over the work of Project SP-3, a joint task force of the Edison Electric Inst. and the joint committee was organized to gather and correlate relevant work being carried on in various agencies on the use of austenitic steels for steam line service. This task force will make recommendations to the Steam Power Panel as to what additional work, if any, should be undertaken.

Test Methods Panel (*J. J. Kanter, chairman*):

Difficulty in reaching some agreement concerning temperature control in high-temperature testing under Recommended Practices E 21, E 22, and E 85 has seriously hampered the completion of revisions of these recommended practices. As a consequence, the organization of a Panel Discussion on Temperature Measurements in Creep and Rupture Testing, to be held at the current Annual Meeting of ASTM, was undertaken to clarify the matter as much as possible.

Respectfully submitted on behalf of the committee,

F. B. FOLEY,
Chairman.
V. T. MALCOLM.
Vice-Chairman.

HOWARD C. CROSS,
Secretary.

REPORT OF COMMITTEE C-1

ON

CEMENT*

Committee C-1 on Cement held three meetings during the past year: in Chicago, Ill., on June 15, 1954; in Jackson, Miss., on October 8, 1954; and in Cincinnati, Ohio, on February 1, 1955. During the Jackson, Miss., meetings the committee members had the opportunity of visiting the new mill and laboratory of the Marquette Cement Manufacturing Co. at Brandon. Visits were also made to three of the projects of the Corps of Engineers, U. S. Army: the soils laboratory at Vicksburg, the Mississippi River hydraulic testing model, and the Concrete Division laboratory, both at Clinton.

The committee records with sorrow the death of two of its members: George W. John and Roderick B. Young. Mr. John represented the Petoskey Portland Cement Co.; Mr. Young was a representative of the Hydro-Electric Power Commission of Ontario and had been a member of the committee since 1919, serving as secretary from 1922 to 1926.

RECOMMENDATIONS ACCEPTED BY THE ADMINISTRATIVE COMMITTEE ON STANDARDS

Subsequent to the 1954 Annual Meeting, Committee C-1 presented to the Society through the Administrative Committee on Standards the following recommendations:

New Tentative Method of Test for:

Flexural Strength of Hydraulic Cement Mortars (**C 348 - 54 T**), and

Compressive Strength of Hydraulic Cement Mortars (Using Portions of Prisms Broken in Flexure) (**C 349 - 54 T**).

Revision and Reversion to Tentative of Standard Method of Test for:

Compressive Strength of Hydraulic Cement Mortars (Using 2-in. Cube Specimens) (**C 109 - 52**).

Withdrawal of Tentative Method of Test for:

Time of Setting of Hydraulic Cement in Mortar (**C 229 - 52 T**).

These recommendations were accepted by the Standards Committee on September 28, 1954, and the new and revised methods appear in the 1954 Supplement to Book of Standards, Part 3.

NEW TENTATIVES

The committee recommends that the following specification and method of test be accepted for publication as tentative as appended hereto:[1]

Tentative Specifications for Slag Cement. This tentative is the result of considerable study of related data by a special subcommittee appointed for the purpose.

Tentative Method of Test for False Set of Portland Cement. This tentative is the result of study of related data and consideration of the results of cooperative tests by various laboratories.

REVISION OF TENTATIVES

The committee recommends for revision and continuation as tentative the following:

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* Presented at the Fifty-eighth Annual Meeting of the Society, June 26–July 1, 1955.

[1] The new tentatives appear in the 1955 Book of ASTM Standards, Part 3.

Tentative Method of Test for Air Content of Hydraulic Cement Mortar (C 185 - 53 T):[2]

Section 2.—Change Paragraph (*j*) to read as follows:

> (*j*) *Tapping stick*, made of maple wood and having a square cross-section of ⅝-in. and a length of 6-in.

Add the following new Paragraph (*k*):

> (*k*) *Spoon.*—A metal kitchen-type spoon with handle cut off to make the over-all length approximately 9 in. and with the bowl of the spoon being approximately 4 in. long, 2½ in. in width at widest portion and ½ to ¾ in. deep.

Section 5(*a*).—In the first sentence, change the weight of cement from "300 g" to read "350 g," and the weight of standard sand from "1200 g" to read "1400 g;" also delete the words "in multiples of 3 ml."

Section 5(*c*).—At the beginning of the second sentence, add the words "Using the spoon." In the fifth sentence, delete the words "of a trowel (held nearly perpendicular to the mold)."

Section 5(*d*).—Replace the third sentence by the following two sentences:

> Using the spoon, place the mortar gently into the 400-ml measure in three equal layers, spading each layer 20 times with the spatula in one complete revolution around the inner surface of the measure. One complete up and down motion of the spatula held in a vertical position shall be considered one spading.

Change the sixth sentence to read as follows:

> After the measure has been filled and spaded in the above prescribed manner, tap the sides of the measure lightly with the flat side of the tapping stick once each at five different points at approximately equal spacing around the outside of the measure in order to preclude entrapment of extraneous air.

Section 6.—Because of the changes above recommended in the batch weights in Section 5(*a*), change the formula to read as follows:

Air content, per cent by volume

$$= 100 - W \frac{(182.7 + P)}{(2000 + 4P)}$$

Tentative Specification for Flow Table for Use in Tests of Hydraulic Cements (C 230 - 52 T):[2]

Section 1.—Delete the note, which is covered by other revisions below.

Section 2(*a*).—Change the first sentence to read: "The flow table apparatus shall be constructed in accordance with Fig. 1." Change the latter part of the third sentence, after the word "vertically," to read "through the specified height with a tolerance in height of ±0.005 in. for new tables and ±0.015 in. for tables in use, by means of a rotated cam." In the next to the last sentence, delete the tolerance in thickness of table top, "0.05 in.," which tolerance is not helpful.

Figure 1.—To avoid overlapping tolerances and provide for proper maintenance of clearance, show the vertical shaft diameter as "0.623 ± 0.001" and remove the tolerances in bore diameter. Make all necessary changes in the details of the figure to make them conform to the revisions now being recommended for this tentative specification. Delete Note 2 and renumber Note 3.

Section 2.—Change the second sentence of Paragraph (*b*) to read as follows:

> The shaft shall be straight and the difference between the diameter of the shaft and the diameter of the bore of the frame shall be not less than 0.002 in. and not more than 0.003 in. for new tables and shall be maintained at from 0.002 to 0.010 in. for tables in use.

In the fourth sentence of Paragraph (*b*), change "perceptible" to "appreciable," and in the last sentence insert "maintained smooth," just before "plane."

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[2] 1953 Supplement to Book of ASTM Standards, Part 3.

In the last sentence of Paragraph (*c*), change "have a machined face" to read "be ground to secure a complete contact with the steel plate beneath."

Add a new Paragraph (*d*) consisting of the present Note 2 of Fig. 1, which note has been recommended above for deletion from the figure, and add the following new Paragraph (*e*):

> (*e*) The performance of a flow table shall be considered satisfactory if, in calibration tests, the table gives a flow value that does not differ by more than 5 percentage points from flow values obtained with a suitable calibration material.[a]
>
> [a] Such a material may be obtained from the Cement Reference Laboratory at the National Bureau of Standards, Washington 25, D. C.

Section 3(*a*).—Change the third and fourth sentences to read as follows:

> The plate shall be anchored to the top of a concrete pedestal by four ½-in. bolts that pass through the plate and are imbedded at least 6 in. in the pedestal. The pedestal shall be cast inverted on the base plate. A positive contact between the base plate and the pedestal shall be obtained at all points.

Change the seventh and eighth sentences to read as follows:

> The pedestal shall be 10 to 11 in. square at the top, and 15 to 16 in. square at the bottom, 25 to 30 in. in height, and shall be of monolith construction, cast from concrete weighing at least 140 lb per cu ft.

Revise the last two sentences to read as follows:

> A stable gasket cork pad, ½ in. thick and approximately 4 in. square, shall be inserted under each corner of the pedestal. The flow table shall be checked frequently for levelness of table top, stability of pedestal, and tightness of bolts and nuts in table base and pedestal plate. (A torque of 20 ft-lb is recommended when tightening those fastenings.)

New Section.—Renumber the present Section 4 as Section 5, and add a new Section 4 to read as follows:

> 4. The vertical shaft of the table shall be kept clean and shall be lightly lubricated with a light oil (SAE-10). Oil shall not be present between the contact faces of the table top and the supporting frame. Oil on the cam face will lessen wear and promote smoothness of operation. The table should be operated a dozen or more times just prior to use if it has not been operated for some time.

Tentative Method of Test for Bleeding of Cement Pastes and Mortars (C 243 – 53 T):[2]

Section 4(*a*).—In the second sentence, change the present batch weights of "... 750 g of cement and 1875 g of natural silica sand ..." to read "930 g" and "2325 g" respectively.

Tentative Method of Test for Calcium Sulfate in Hydrated Portland Cement Mortar (C 265 – 54 T):[3]

Add to the end of the method the following note:

> NOTE.—The work on which this method is based indicated that the optimum amount of SO_3 in the cement is that which would yield an extract containing between 0.1 and 0.5 gram SO_3 per liter.

Tentative Method for Mechanical Mixing of Hydraulic Cement Mortars of Plastic Consistency (C 305 – 53 T):[2]

Section 2.—In the last sentence of Paragraph (*a*), after the word "approximately," insert the words "0.1-in., but not less than."

In the last sentence of Paragraph (*b*), change the words "not exceed $\frac{5}{32}$-in." to read "approximately $\frac{5}{32}$-in., but shall not be less than 0.03-in."

Add a new sentence at the end of the section of Paragraph (*c*) to read: "There shall be provided a lid, made of nonabsorbing material not attacked by the cement."

Change the designation of present Paragraph (*d*) to (*e*) and add the following new Paragraph (*d*):

> (*d*) *Scraper.*—The scraper shall consist of a semirigid rubber blade attached to a handle about 6 in. long. The blade shall be about 3 in.

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[3] 1954 Supplement to Book of ASTM Standards, Part 3.

long, 2 in. wide, and tapered to a thin edge about $\frac{1}{16}$ in. thick.

NOTE.—A kitchen tool known as a plate and bowl scraper conforms to these requirements.

Section 3.—Secure a clearer and more realistic wording by making the first sentence read: "The temperature of the room shall be maintained between 20 and 27.5 C (68 and 81.5 F), and the temperature of the dry materials, paddle and bowl shall be within the above range at the time of test."

Section 5.—Revise the first sentence to read: "Place the dry paddle and the dry bowl in the mixing position in the mixer."

In Subparagraph (5), line 8, change "a" to "the" in the reference to the lid.

Add a new Subparagraph (7) to read as follows:

> (7) In any case requiring a remixing interval, any mortar adhering to the side of the bowl shall be quickly scraped down into the batch with the scraper prior to remixing.

Change the Caution note to read as follows:

> **Caution.**—The herein specified clearances between paddle and bowl are suitable when using the standard mortar made with Ottawa Sand. Caution is invited when using much coarser aggregates which may require special clearances to permit the mixer to operate freely and to avoid serious damage to the paddle and bowl.

Figure 1.—For the sake of uniformity in manner of expression, change "2.752" to read "2$\frac{3}{4}$."

Tentative Specifications for Portland-Pozzolan Cement (C 340 - 54 T):[3]

Section 3(a).—Add a note to read as follows:

> NOTE.—The attainment of an intimate and uniform blend of portland cement and fine pozzolan is difficult. Consequently, adequate equipment and controls must be provided by the manufacturer. The purchaser should assure himself of the adequacy of the blending operation.

Section 11.—After the first sentence add the following:

> The manufacturer shall provide suitable facilities to enable the inspector to check the relative weights of portland cement and pozzolan, and the blending operation used to produce the portland-pozzolan cement. The plant facilities for blending and inspection shall be adequate to insure compliance with the requirements in Section 3(*a*).

Table I.—Delete the moisture content requirement.

Section 13.—In Paragraph (*a*), item (*5*), delete the words "and moisture content." In Paragraph (*b*), item (*3*), delete the words "except that the value so obtained minus the moisture content shall be reported as loss on ignition;" and delete item 4 of Paragraph (*b*).

Table II.—Express the water requirement on basis of percentage, by weight, of the cement, instead of in terms of volume of water, making the following appropriate changes: Replace "ml" by "per cent, by weight of the cement," and change values "320" and "280" to read "64" and "56," respectively.

REVISION OF STANDARD AND REVERSION TO TENTATIVE

The committee recommends that the following standard be revised and reverted to tentative status:

Standard Methods of Sampling Hydraulic Cement (C 183 - 46):[4]

Sections 2 and 3.—Provide for a necessary increase in the size of sample as follows: Change "4 lb" to "5 lb" in Sections 2(*a*), 3(*a*), 3(*b*); change "8 lb" to "10 lb" in Section 2(*a*).

In order to conform to the current custom of expressing quantities of cement in terms of barrels, make the following revisions: Change "2000 bags" to read "500 barrels" in Sections 2(*b*), 3(*a*), 3(*b*), and 3(*d*). In Section

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[4] 1952 Book of ASTM Standards, Part 3.

3(*a*) change "40 bags" to "10 barrels," and in Section 3(*d*) change "50 bags" to "15 barrels."

Section 5.—Change the title of this section to read "Number of Physical Tests and Chemical Determinations."

In Paragraph (*a*), change "2000 bags" to read "500 barrels."

In Paragraphs (*b*) and (*c*) secure a very desirable change (an increase in most cases) in the quantities of cement to be represented by the respective tests and also achieve almost complete uniformity on this point between Federal and ASTM requirements, by rewording these two sections to read as follows:

> (*b*) Physical tests on samples taken from bins, boats, warehouses, etc., shall be required as follows:
>
> Tests for time of setting, air content, fineness, strength, and soundness shall be made on each test sample representing each 2000 barrels.
>
> (*c*) All specified chemical determinations shall be made on each test sample representing each 2000 barrels.

ADOPTION OF TENTATIVE AS STANDARD WITH REVISION

The committee recommends that the Tentative Method of Test for Heat of Hydration of Portland Cement (Short Method) (**C 186 – 54 T**)[3] be approved for reference to letter ballot of the Society for adoption as standard with revisions as appended hereto.[5]

The method was published as tentative in 1954 and is essentially the same as the corresponding short method in the Federal Methods of Test, SS-C-158c. The revised method is to replace the current Standard Method of Test for Heat of Hydration of Portland Cement (C 186 – 53).

ADOPTION OF TENTATIVE AS STANDARD WITHOUT REVISION

The committee recommends that the Tentative Definition of the Term Pozzolan (**C 219 – 53 T**)[2] be approved for reference to letter ballot of the Society for adoption as standard without revision, which involves its incorporation into the Standard Definition C 219 – 53, the title of which will be changed to Standard Definitions of Terms as Applied to Hydraulic Cement.

ADOPTION OF TENTATIVE REVISION AS STANDARD

The Committee recommends that tentative revisions of the following standards be approved for reference to letter ballot of the Society for adoption as standard:

Standard Specifications for Masonry Cement (C 91 – 53):[2]

Tentative revisions issued June, 1953, with respect to Sections 3 and 18, and tentative revisions issued September, 1953, with respect to Sections 19, 23, and 30(*a*) with the following modification of the revision of Section 30(*a*):

Replace the fourth sentence with the following:

> A synthetic rubber gasket shall be permanently sealed to the top of the funnel and shall be lightly coated with petrolatum or light cup grease during a test to insure a seal between the funnel and dish. (Care should be taken to insure that none of the holes in the perforated dish are clogged from the grease used on the rubber gasket.)

The tentative revision issued September, 1953, with respect to Section 30 (*b*) is not being recommended for adoption to Standard, but is intended to be replaced by a revision that is recommended elsewhere in this report for immediate adoption.

Standard Method of Test for Normal Consistency of Hydraulic Cement (C 187 – 49):[4]

Tentative revision issued September, 1953, with respect to Section 4(*c*) which was designed to define a reasonable tolerance in the required penetration of the Vicat plunger.

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[5] The revised tentative appears in the 1955 Book of ASTM Standards, Part 3.

Standard Method of Test for Fineness of Portland Cement by Air Permeability Apparatus (C 204 – 51):[4]

Tentative revision issued June, 1953, with respect to Sections 3(*b*), 3(*e*), 3(*g*), 5, and Table I.

REVISIONS OF STANDARD, IMMEDIATE ADOPTION

The committee recommends for immediate adoption the following revisions of standards and accordingly asks for the necessary nine-tenths affirmative vote at the Annual Meeting in order that the revisions may be referred to letter ballot of the Society:

Standard Specifications for Portland Cement (C 150 – 53):[2]

Table I.—Delete the current limitations on calcium sulfate in hydrated portland cement mortar, and add the current Federal Specification limits on sulfur trioxide, as follows:

	Types				
	I	II	III	IV	V
When $3CaO \cdot Al_2O_3$ is 8 per cent or less, max, per cent	2.5	2.5	3.0	2.3	2.3
When $3CaO \cdot Al_2O_3$ is more than 8 per cent, max, per cent	3.0	...	3.0	...	...

Table II.—Change the compressive strength requirements to read as follows for the various ages:

Age, days	Types				
	I	II	III	IV	V
1	...	...	1700	...	...
3	1200	1000	3000	...	...
7	2100	1800	...	800	1500
28	3500	3500	...	2000	3000

Section 10.—Delete Paragraph (*c*) and reletter subsequent paragraphs.

Standard Specifications for Air-Entraining Portland Cement (C 175 – 53):[4]

Table I.—Delete the current limitations on calcium sulfate in hydrated portland cement mortar, and for the three types of cement, types IA, IIA and IIIA, insert in the table the same limitations on sulfur trioxide as recommended above for types I, II and III, respectively in Specifications C 150.

Table II.—Change the compressive strength requirements for types IA and IIA to read as follows for the various ages:

Age, days	Type	
	IA	IIA
3	900	750
7	1500	1400
28	2800	2800

Change the current limitation on the air content of the standard mortar from "18 ± 3 per cent" by volume to "19 ± 3 per cent" for all three types of cement.

Section 10.—Delete Paragraph (*c*) and reletter subsequent paragraphs.

Standard Specifications for Masonry Cement (C 91 – 53):[2]

Section 19.—Reletter the present Paragraph (*j*) as (*k*) and add the following new Paragraph (*j*):

> (*j*) *Straight Edge.*—A steel straight edge not less than 8 in. long and not less than $\frac{1}{16}$ nor more than $\frac{1}{8}$ in. in thickness.

Section 30(b).—Change to read as follows:

> Adjust the mercury relief column so as to maintain a vacuum of 2 in. as measured on the manometer. Seat the perforated dish on the greased gasket of the funnel. Place a wetted filter paper in the bottom of the dish. Turn the stopcock to apply the vacuum to the funnel and check the apparatus for leaks and determine that the required suction is obtained. Then turn the stopcock to shut off the vacuum from the

funnel. Now mix the mortar to a flow of 100 to 115 per cent in accordance with the procedure described in Section 23(*b*). Immediately after making the flow test, the mortar on the flow table shall be returned to the mixing bowl and the entire batch remixed for 15 seconds. Immediately after remixing of the mortar, the perforated dish shall be filled with the mortar to slightly above the rim. The mortar shall then be tamped 15 times with the tamper. Ten of the tamping strokes shall be applied at approximately uniform spacing adjacent to the rim of the dish and with the long axis of the tamping face held at right angles to the radius of the dish. The remaining 5 tamping strokes shall be applied at random points distributed over the central area of the dish. The tamping pressure shall be just sufficient to insure uniform filling of the dish. On completion of the tamping, the top of the mortar should extend slightly above the rim of the dish. The mortar shall be smoothed off by drawing the flat side of the trowel (with the leading edge slightly raised) across the top of the dish The mortar shall then be cut off to a plane surface flush with the rim of the dish by drawing the straight-edge with a sawing motion (starting from the center of the dish) across the top of the dish. If the mortar is pulled away from the side of the dish during the process of drawing the straightedge across the dish, the mortar shall be gently pressed back into contact with the side of the dish using the tamper. Then turn the stopcock to apply the vacuum to the funnel. The time elapsed from the start of mixing the cement and water to the time of applying the vacuum shall not exceed 8 min. After suction for 60 seconds the stopcock shall be quickly turned to expose the funnel to atmospheric pressure. Immediately slide the perforated dish off from the funnel, touch it momentarily upon a dampened cloth for the purpose of removing the droplets of water clinging to the bottom of the dish and quickly overturn the dish upon a dry, smooth, nonabsorbent surface to remove the mortar. Mix the mortar with the flat side of the trowel for 15 seconds. Upon completion of mixing, the mortar shall be placed in the flow mold and the flow determined. The entire operation shall be carried out without interruption and as quickly as possible, and shall be completed within an elapsed time of 11 min after the start of mixing the cement and water for the first flow determination. Both flow determinations shall be made in accordance with the procedure described in Section 24.

The revision of Section 30(*b*) was designed to promote refinement and uniformity in those details that had been considered important in making the water retention test, and is intended to embody and replace the tentative revision that was issued in September, 1953.

TENTATIVES CONTINUED WITHOUT REVISION

The committee recommends that the following five tentatives be continued without change at this time, except for an editorial change as hereinafter proposed for Tentative Method C 227 - 52 T. Most of these tentatives are the subjects of current study within the committee.

Tentative Methods of Test for:

Potential Alkali Reactivity of Cement-Aggregate Combinations (**C 227 - 52 T**),
Sodium Oxide and Potassium Oxide in Portland Cement by Flame Photometry (**C 228 - 49 T**),
Time of Setting of Hydraulic Cement by Gillmore Needles (**C 266 - 51 T**).

Tentative Methods of Chemical Analysis for:

Portland Cement (C **114 - 51 T**).

Tentative Specifications for:

Portland Blast-Furnace Slag Cement (**C 205 - 53 T**).

REAPPROVAL OF STANDARDS

The committee recommends reapproval of the following four standards which have been published for six years or longer without revision:

Standard Method of Test for:

Fineness of Hydraulic Cement by the No. 200 Sieve (**C 184 - 44**),
Specific Gravity of Hydraulic Cement (**C 188-44**),
Soundness of Hydraulic Cement over Boiling Water (Pat Test) (**C 189 - 49**), and
Tensile Strength of Hydraulic Cement Mortars (**C 190 - 49**).

EDITORIAL CHANGES

The committee recommends editorial changes in the following two test methods:

Standard Method of Test for Autoclave Expansion of Portland Cement (C 151 - 54):[3]

In order to ensure that the users of this method may have at hand certain precautions related to this test, it is recommended that there be appended, at the end of the test method, the following abstract of the related material that now forms part of the ASTM Manual on Cement Testing, which publication may not be available to some laboratories. The recommended revision is as follows:

Change the "Caution" note at the beginning of the Method to read as follows: **Caution.**—For safety precautions to be observed in making autoclave tests of cement, see Appendix to this Method.

Appendix.—Add an Appendix consisting of Sections 38 to 44 of the Manual of Cement Testing.

Tentative Method of Test for Potential Alkali Reactivity of Cement-Aggregate Combinations (C 227 - 52 T):[4]

In order to effect a very desirable clarification in the instructions for molding the test specimens, the following editorial change is recommended:

Section 5(*e*).—Add the following sentence: "Bars for expansivity test specimens shall not be made of material which has previously been used for the flow test."

Standard Methods of Chemical Analysis of Portland Cement (C 114 - 53):[2]

Detailed editorial changes have been made for further refinement and clarification of the standard.

Tentative Methods of Chemical Analysis of Portland Cement (C 114 - 51 T):[4]

For purposes of clarification and simplification, editorial changes are recommended, including a new section on Scope and the incorporation of the Method of Test for Sodium Oxide and Potassium Oxide by Flame Photometry, Using the Direct-Intensity Method (C 228 - 49 T),[4] with the resulting withdrawal of Method C 228.

The recommendations in this report have been submitted to letter ballot of the committee, the results of which will be reported at the Annual Meeting.[6]

Activities of Subcommittees

During the year the various subcommittees have been engaged in studying questions of importance in their respective fields. Among the subjects have been those relating to air-entrainment of masonry cement, development of a specification for slag cement, devising a tentative test for false set, bleeding of cement pastes and mortars, strength limits in cement specifications, requirements for testing apparatus, refinements of test methods. In connection with the study of the strength requirements of the cement specifications and the related test methods, there was made a very extensive, country-wide survey of the strengths of different portland cements as reported by the many different laboratories. The results were assembled, summarized, and studied as the basis of certain recommendations. The activities of the subcommittees were summarized briefly in the January ASTM Bulletin, and the extent of the work is indicated by the numerous recommendations that have been presented in this report.

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[6] The letter ballot vote on these recommendations was favorable; the results of the vote are on record at ASTM Headquarters.

This report has been submitted to letter ballot of the committee, which consists of 89 voting members; 76 members returned their ballots, of whom 75 have voted affirmatively and 0 negatively.

Respectfully submitted on behalf of the committee,

R. R. LITEHISER,
Chairman.

W. S. WEAVER,
Secretary.

EDITORIAL NOTE

Subsequent to the Annual Meeting, Committee C-1 presented to the Society through the Administrative Committee on Standards the recommendation that the Standard Specifications for Masonry Cement (C 91 – 55) be revised and reverted to tentative status. This recommendation was accepted by the Standards Committee on September 15, 1955, and the revised specifications appear in the 1955 Book of ASTM Standards, Part 3, and in the 1955 Compilation of ASTM Standards on Cement.

APPENDIX I

COOPERATIVE TEST PROGRAM TO INVESTIGATE THE EFFECT OF MECHANICAL MIXING ON THE COMPRESSIVE- AND FLEXURAL-STRENGTH OF PORTLAND CEMENT MORTARS

SPONSORED BY WORKING COMMITTEE ON STRENGTH OF COMMITTEE C-1

In anticipation of the acceptance by Committee C-1 on Cement of mechanical mixing for mortars recommended by the Working Committee on the Coordination of Tests, it was decided at the meeting of the Working Committee on Strength in Detroit, Mich., on March 3, 1953, to undertake a cooperative series of tests to determine:

1. The effect that mechanical mixing would have on the compressive strength as developed by mortar cubes made by ASTM Method of Test C 109,[1] and the relationship of such strengths on the specified requirements for compressive strength in ASTM Specifications C 150[2] and C 175.[3]

2. The effect of mechanical mixing on the strength developed by the ASTM Tentative Method of Test for Compressive Strength of Hydraulic-Cement Mortars (Using Portions of Prisms Broken in Flexure) (C 349)[4] and the ASTM Tentative Method of Test for Flexural Strength of Hydraulic-Cement Mortars (C 348).[5]

In addition to the above primary purposes, it was decided to incorporate into the program the use of a penetration test for the determination of consistency and a modified briquet apparatus for testing mortar prisms in flexure. This provided for a comparison of the penetration test with the currently used flow test of Method of Test C 109 for consistency and comparison of the modified briquet apparatus with the flexural testing device for mortar prisms used with hydraulic testing machines.

The following nine laboratories participated in this cooperative investigation:

Bureau of Reclamation, Denver, Colo. (W. T. Moran)
California Highway Dept., Sacramento, Calif. (Bailey Tremper)
Ideal Cement Co., Fort Collins, Colo. (G. C. Wilsnack)
Illinois Highway Dept., Springfield, Ill. (J. D. Lindsay)
Marquette Cement Mfg. Co., Des Moines, Iowa (F. S. Reagel)
National Bureau of Standards, Washington, D. C. (R. L. Blaine)
Penn-Dixie Cement Corp., Nazareth, Pa. (L. C. Hawk)
Portland Cement Assn., Skokie, Ill. (T. M. Whiteside)
Universal Atlas Cement Co., Buffington, Ind. (W. C. Hansen)

The laboratories are not listed above in the order in which their results appear in the tabulation of test data.

MATERIALS

Eight portland cements, two each from four different manufacturers, were furnished to each laboratory. Each cement was carefully blended and split into duplicate samples. Each laboratory received a minimum of 34 lb of each cement. The cements are identified as follows:

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[1] Tentative Method of Test for Compressive Strength of Hydraulic Cement Mortars (Using 2-in. Cube Specimens) (C 109 - 54 T), 1954 Supplement to Book of ASTM Standards, Part 3, p. 16.

[2] Specifications for Portland Cement (C 150 - 53), 1953 Supplement to Book of ASTM Standards, Part 3, p. 1.

[3] Specifications for Air-Entraining Portland Cement (C 175 - 53), 1952 Book of ASTM Standards, Part 3, p. 6.

[4] 1954 Supplement to Book of ASTM Standards, Part 3, p. 23.

[5] 1954 Supplement to Book of ASTM Standards, Part 3, p. 26.

Cement	Type
No. 20	II
No. 21	II
No. 22	IA
No. 23	III
No. 24	IA
No. 25	III
No. 26	I
No. 27	I

In addition, seven of the nine participating laboratories obtained from their local market two brands of cement, which were tested only in that laboratory. These cements are identified in the following manner:

Laboratory	Cement	Type
C	No. 28	III
C	No. 29	I
D	No. 30	IA
D	No. 31	I
E	No. 32	III
E	No. 33	II
H	No. 34	I
H	No. 35	III
I	No. 36	I
I	No. 37	IA
F	No. 40	I
F	No. 41	IA
B	No. 44	IA
B	No. 45	I

It is evident from the foregoing that ASTM types I, IA, II, and III cements were represented in the program as follows:

Type I	8
Type II	3
Type IA	6
Type III	5
Total	22

The graded Ottawa sand was furnished by each laboratory from its own supply.

Duplicate paraffin-treated hardwood tampers were furnished each laboratory for use in the preparation of mortar prisms.

DESCRIPTION OF TESTS

Each laboratory was *scheduled* to make three rounds of tests, generally each one on different days, each test round consisting of the following tests and procedures:

Compressive Strength of C 109 Mortar:

Hand-Mixing Procedure.—Three sets of 2-in. cubes (9-cube batch) prepared and tested by ASTM Method of Test C 109-52.[6] Three specimens each tested at 3, 7, and 28 days for types I, IA, and II cements and at 1, 3, and 7 days for type III cements.

Machine-Mixing Procedure.—Three sets of 2-in. cubes (9-cube batch) prepared and tested by Method of Test C 109-52 except that the mixing procedure for mechanical mixing in Appendix A was substituted for the hand-mixing procedure in the Method of Test C 109. Three specimens each tested at 3, 7, and 28 days for types I, IA, and II cements and at 1, 3, and 7 days for type III cements.

Flexural Strength of Mortar:

Six 2-in. prism specimens prepared in accordance with the Tentative Method of Test for Flexural Strength of Hydraulic-Cement Mortars (C 348).[5] Two beams tested in flexure (two tests per beam) at 3, 7, and 28 days for types I, IA, and II cements and at 1, 3, and 7 days for type III cements.

It was agreed that four laboratories would test the beams in flexure using hydraulic testing machines, three laboratories would use the modified briquet apparatus only, and two laboratories would test by both types of apparatus. The modified briquet apparatus and flexural loading frames used with hydraulic testing machines are described and illustrated in Method of Test C 348.

Compressive Strength of Modified 2-in. Mortar Cubes:

Portions of the mortar prisms remaining after the prisms were tested in flexure were to be tested in compression as modified 2-in. cubes (see Method of Test C 349).[4] Three tests were to be made per beam (two beams per test age).

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[6] Method of Test for Compressive Strength of Hydraulic Cement Mortars (C 109 – 52), 1952 Book of ASTM Standards, Part 3, p. 119.

Penetration Consistency Test:

A penetration test, conforming to Sections 2(*d*), 2(*e*), 4(*c*), 4(*d*) of ASTM Tentative Method of Test for Time of Setting of Hydraulic Cement in Mortar (C 229 – 51 T)[7] except that only one penetration test was required, was to be made on each mortar batch after the C 109 flow (range 100 to 115 per cent) was obtained.

Miscellaneous Tests:

Each laboratory furnishing cement was requested (1) to furnish complete chemical and physical test data on their cements, (2) to calibrate their flow tables with the CRL calibration material at the start of the test series, and (3) to furnish the sieve analyses (including the 40-mesh sieve) of each bag of graded Ottawa sand used.

DISCUSSION OF RESULTS

NOTE.—The data for types I and II cement are combined in the statistical treatment. Where type I is referred to hereinafter, it includes the data from the type II cements.

Hand Mixing versus Machine Mixing:

ASTM Method of Test C 109.—The differences in compressive strengths and water requirements between hand-mixed and machine-mixed mortars at each test age for all cements were calculated. The standard errors of these differences were calculated in order to determine if the average differences obtained were significantly different from differences that would have occurred due to chance (due to the error inherent in the test methods and procedures). A comparison of the average differences with the standard error of these differences by the "*t*-test" (ratio of the difference to the standard error of the difference) for a 95 per cent probability level indicated the differences that occurred between the hand-mixing and machine-mixing procedures (see Table A).

Comparison of the hand-mixed and machine-mixed data indicated that the differences in reproducibility between the two methods of test are not statistically significant.

Modified Cube.—The compressive strengths and water requirements of mortar used for modified cubes were compared with the hand-mixed C 109 mortars. The significant differences between the hand-mixed C 109 results and the machine-mixed modified cube results are summarized in Table B.

Comparison of the standard deviations of the hand-mixed C 109 test results and the machine-mixed modified cube test results indicated that the differences in reproducibility of the two methods are not statistically significant.

A similar comparison between machine-mixed C 109 mortars and the modified cubes is given in Table C.

Modified Briquet Apparatus versus Flexural Testing Device Used with Hydraulic Testing Machines:

The flexural strength results obtained by the two methods of test used in this program were averaged and analyzed separately. The flexural strength results for the locally procured types IA and III cements were not averaged separately on the basis of the two methods of test since the population of data was too limited. The differences in flexural strength results obtained by each method were obtained. Comparison of these average differences with the standard error of the difference indicated that significant differences, shown in Table D, occurred between the two flexural testing methods.

Comparison of the standard deviations for the modified briquet apparatus and hydraulic testing machine results indicated that the differences in reproducibility of the two methods are not statistically significant.

Penetration Test for Consistency:

The average water content, C 109 flow, and results obtained by the penetration test method showed, for type I cement mortars, very little difference in the consistency, as indicated by the average flow and penetration results, or in reproducibility of the test

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[7] 1951 Supplement to Book of ASTM Standards, Part 3, p. 47.

TABLE A.—AVERAGE DIFFERENCES[a] BETWEEN HAND-MIXING AND MACHINE-MIXING PROCEDURES.

	Compressive Strength, psi			Mixing Water, per cent
	3 days	7 days	28 days	
TYPE I				
Average difference	+285	+350	+363	−0.5[b]
Difference expressed as a percentage of the hand-mixed C 109 strength	+14	+11	+8	...
TYPE IA				
Average difference	+49[b]	−9[b]	−181[b]	−1.3
Difference expressed as a percentage of the hand-mixed C 109 strength	+3[b]	−0.3[b]	−4[b]	...
TYPE III				
	1 day	3 days	7 days	
Average difference	+192	+351	+348	−0.7[b]
Difference expressed as a percentage of the hand-mixed C 109 strength	+11	+10	+7	...

[a] Machine mixing minus hand mixing.
[b] These differences were not statistically significant.

TABLE B.—AVERAGE DIFFERENCE[a] BETWEEN HAND-MIXED C 109 RESULTS AND MACHINE-MIXED MODIFIED CUBE RESULTS.

	Compressive Strength, psi			Mixing Water, per cent
	3 days	7 days	28 days	
TYPE I				
Average difference	+511	+517	+521	−0.1[b]
Difference expressed as a percentage of the hand-mixed C 109 strength	+25	+17	+11	...
TYPE IA				
Average difference	+113[b]	−33[b]	−324	−0.8
Difference expressed as a percentage of the hand-mixed C 109 strength	+6[b]	−1[b]	−8	...
TYPE III				
	1 day	3 days	7 days	
Average difference	+224	+268	+83[b]	−0.3[b]
Difference expressed as a percentage of the hand-mixed C 109 strength	+13	+8	+2[b]	...

[a] Machine mixing minus hand mixing.
[b] These differences were not statistically significant.

methods as measured by the standard deviations between the hand-mixing and machine-mixing procedures. The coefficient of variation indicated that the relative dispersions of the penetration test results are greater than the flow test results.

Similarly, for types IA and III cement mortars, the average level and reproducibility of the C 109 flow test results remained essentially the same between hand- and machine-mixing methods. However, in direct contrast, the level and reproducibility of the penetration test results changed significantly. For type IA cement mortars, the average level of the penetration results increased significantly for machine mixing. If the type IA mortars had been mixed to a constant penetration instead of constant flow, an even further reduced water content for machine mixing of type IA cement mortars would have been required. This would also result in the development of a different strength relationship between hand-mixing and machine-mixing procedures. For both machine mixing and hand mixing with types IA and III cement, the apparent reproducibility of the penetration test results has significantly decreased. However, this may indicate that the penetration test is more sensitive to small changes in consistency. Additional data are required to determine why the penetration results are apparently less reproducible for types IA and III cement mortars than for type I mortars. For all comparisons, the coefficients of variation indicated that the penetration method test results have a larger relative dispersion than the C 109 flow test results. This may be due to desirably greater sensitivity in the penetration test.

TABLE C.—AVERAGE DIFFERENCE[a] IN WATER REQUIREMENT AND COMPRESSIVE STRENGTHS BETWEEN MACHINE-MIXED C 109 MORTARS AND MACHINE-MIXED MODIFIED CUBE MORTARS.

	Compressive Strength, psi			Mixing Water, per cent
	3 days	7 days	28 days	
TYPE I				
Average difference	+226	+167[b]	+158[b]	0.4[b]
Difference expressed as percentage of machine-mixed C 109 results	+11	+6[b]	+3[b]	...
TYPE IA				
Average difference	+65[b]	−25[b]	−143[b]	0.4[b]
Difference expressed as percentage of machine-mixed C 109 results	+3[b]	−0.7[b]	−4[b]	...
TYPE III				
	1 day	3 days	7 days	
Average difference	+32[b]	−83[b]	−265	0.4[b]
Difference expressed as percentage of machine-mixed C 109 results	+2[b]	−2[b]	−5	...

[a] Modified-cube minus machine-mixed C 109 mortars.

[b] These differences were not statistically significant.

Gradation of Graded Ottawa Sand:

A sieve analysis was made of each sack of sand used in the program. Laboratory D reported the rejection of three sacks of sand for failing to meet the requirement for sand retained on the No. 50 sieve. However, the gradation of the rejected sand was not reported. Laboratory C blended all of the sand required at the start of the program and only reported the gradation of the blend. The sieve analyses reported indicate that 15 out of approximately 92 sacks of sand failed to meet the Method of Test C 109 specification for graded sand. The particular requirements failed by the individual analyses are indicated below:

Number of Sacks	Failed in Specification Requirement with Respect to
0	No. 16 sieve
2	No. 30 sieve
5	No. 50 sieve
3	No. 100 sieve
2	Nos. 50 and 100 sieve

It is also of interest to note that 62 of the 92 sacks failed to meet a possible No. 40 sieve requirement of 35 ± 5 per cent retained. The sieve analysis of the blend used by laboratory C also failed the proposed No. 40 sieve requirement.

TABLE D.—AVERAGE DIFFERENCE[a] BETWEEN MODIFIED BRIQUET APPARATUS AND HYDRAULIC TESTING MACHINE METHODS FOR TESTING FLEXURE SPECIMENS.

	Compressive Strength, psi		
	3 days	7 days	28 days
TYPE I			
Average difference	+15[b]	+4[b]	−10[b]
Difference expressed as a percentage of the hydraulic testing machine method	+3[b]	+0.6[b]	−1[b]
TYPE IA			
Average difference	+29	+25	−10[b]
Difference expressed as a percentage of the hydraulic testing machine method	+7	+4	−1[b]
TYPE III			
	1 day	3 days	7 days
Average difference	+38	+7[b]	+5[b]
Difference expressed as a percentage of the hydraulic testing machine method	+8	+1[b]	+0.6[b]

[a] Modified briquet apparatus results minus hydraulic testing machine results.

[b] These differences were not statistically significant.

Variance of Results Between and Within Laboratories:

Variance Between Laboratories.—The estimates of the variation in test results between laboratories for each cement, as determined by the standard deviations, have been pooled to provide an over-all estimate for each type of cement. As the standard deviation is the square root of a ratio (the ratio of squared deviation to the number of items in the population), it is not additive and cannot be averaged. Therefore, the variance (the variance is equal to the standard deviation squared) was utilized, and a weighted average variance (weighted by the number of items in the population) for all the cements was obtained. The square root of this average variance provides an estimate of the standard deviation that represents the total variation between laboratories for a given type of cement. The pooled or averaged variances and standard deviations calculated therefrom were recorded for each test age and type of cement. These standard deviations estimate the spread in reported results that could be expected if duplicate samples of cement were tested by a number of testing laboratories. The variances of the locally procured cements were not used in the calculation of the average variances.

As the standard deviations are measures of absolute dispersion, they are not strictly comparable. Therefore, the coefficient of variation (the ratio of the standard deviation to the average) was calculated. Comparison of the coefficients of variation indicated that the data obtained in this test series show very little difference in reproducibility of the test methods. *In general, the modulus of rupture test results for the machine-mixed mortar prisms tend to be slightly more reproducible at all ages than the compressive strength test results.* The machine-mixed C 109 compressive strength results tend to be slightly more reproducible than the hand-mixed C 109 compressive strength results or the machine-mixed modified cube test results.

Variance Within Laboratories (Between Days).—The variance of the three individual results (specimens prepared on different days within the same laboratory) were calculated separately for each laboratory and then averaged to obtain a pooled estimate of the variation within the laboratories. The square root of this average variance gives an estimate of the variation within laboratories that can be compared with the estimates of variation between laboratories. Laboratory A results were not used in calculating the within laboratory variance because only one round was completed by this laboratory. Comparison of the variances and standard deviations indicated that, if duplicate samples were tested in a single laboratory instead of different laboratories, the dispersion in results would be approximately halved.

The within laboratory variances can also be pooled separately for each individual laboratory, thereby providing a relative measure of the variation in each laboratory.

CONCLUSIONS

A. Comparison of hand-mixed and machine mixed C 109 compressive strength results indicated:

1. A significant increase, approximately 10 per cent, in compressive strengths due to machine mixing for types I, II, and III cement mortars. The individual differences for each test age tabulated in Table A indicate greater increases at the early test ages and smaller increases at the later test ages.

2. No significant increase or decrease in compressive strength due to mechanical mixing of type IA cement mortars. However, the differences in Table A indicate a slight tendency for a decrease at later test ages, but this difference is not statistically significant. Additional data might indicate a significant difference.

3. No significant increase or decrease in water requirement due to machine mixing of types I, II, and III cement mortars.

4. A significant decrease in water requirements, due to machine mixing, of approximately 1 per cent for type IA cement mortars.

5. No significant difference in the reproducibility of the results from hand- or machine-mixed C 109 test methods. There was a tendency for the machine-mixed results to be more reproducible, but the degree of difference was not large.

B. Comparison of strengths obtained by Method of Test C 109 and by the machine-mixed modified cube method indicated:

1. A large and significant increase in strength of types I and II cement with the machine-mixed modified-cube method as compared with hand-mixed C 109 mortars (Table B). There was a moderate and significant decrease in modified-cube strength for type IA cements at 28-day ages, but the effect of method was insignificant at the

other ages. The modified-cube method developed a significant increase with type III cements, but only of about one half the amount developed by types I and II cements.

There was no significant effect on the water requirement for types I and III cements, but the machine-mixed modified-cube method required significantly less water for type IA cement. There was no significant difference in the reproducibility of the two procedures.

2. A moderately large and significant increase in strengths of type I cement with the machine-mixed modified-cube method as compared with machine-mixed C 109 mortars (Table C). The effect on type IA cements was insignificant at all ages. The effect on type III cement was very slight but significant at the 7-day age.

There was no significant effect on the water requirement, although there was a tendency toward a slight increase for the modified cubes.

There was no significant difference in the reproducibility of the two procedures.

C. Comparison of flexural strength results obtained by the modified briquet apparatus with results obtained by the flexural testing device used with hydraulic testing machines indicated:

1. No significant difference in the results between the two test methods for types I and II cement mortars. The individual differences in Table D were greater for the early ages and tended to decrease at the later test ages, indicating a declining trend with age.

2. A significant increase in the 3- and 7-day flexural strengths of approximately 6 per cent for the modified briquet apparatus test results for type IA cement mortars. The individual differences in Table D indicated a declining trend with increase in test age.

3. A significant increase in the 1-day flexural strength of approximately 8 per cent for the modified briquet apparatus test results on type III cement mortars. Similar to the types I and IA mortars, the individual differences in Table D indicated a declining trend with test age.

4. No statistically significant difference in reproducibility of the two methods of test.

D. Comparison of the coefficients of variation for the various test methods utilized in this test series indicated very little difference in the reproducibility of the various methods of test. *In general, the modulus of rupture test results tended to be slightly more reproducible than the compressive strength test results. The machine-mixed C 109 compressive strength results tended to be slightly more reproducible than the hand-mixed C 109 compressive strength results or the machine-mixed modified-cube test results.*

E. Comparison of the C 109 flow and penetration consistency results indicated:

1. For types I and II cement mortars, the average consistency and reproducibility of each test method remained the same for hand- and machine-mixing. The relative reproducibility was much lower for the penetration test results.

2. For type IA cement mortars, the level and reproducibility of the C 109 flow test results were similar to the type I cement results. In contrast, the average level of the penetration results increased with the machine mixing. The reproducibility of the penetration test results was lower than for type I cement mortars. This lower reproducibility of the penetration test results may indicate that the penetration test method is more sensitive to small changes in consistency than is the C 109 flow method.

3. For type III cement mortars, the level and reproducibility of the C 109 flow test results were similar to the types I and IA results. The difference in penetration between hand- and machine-mixing was not so great as for type IA cement mortars. The lower reproducibility of the penetration results, which is characteristic of the type IA cement mortars, was also characteristic of the type III cement mortar.

F. The sieve analysis results for the Ottawa graded sand used in the program indicated:

1. That 15 out of approximately 92 sacks, or 16 per cent of the graded sand tested, did

not meet the current C 109 specification requirement for graded sand.

2. That 62 out of approximately 92 sacks, or 67 per cent of the graded sand tested, would not meet a possible 40-mesh requirement of 35 ± 5 per cent retained.

E. Analysis of the variation in the strength test results between and within laboratories indicated that the variability of test results between laboratories is about twice the variability of results within the laboratories.

Respectfully submitted on behalf of the Working Committee on Strength,

C. E. WUERPEL,
Chairman.

MEMBERS:
R. F. BLANKS
C. L. DAVIS
W. T. MORAN
M. A. SWAYZE
BAILEY TREMPER
T. M. WHITESIDE

APPENDIX II

INVESTIGATION OF THE LEVEL OF STRENGTH DEVELOPMENT OF DOMESTIC PORTLAND CEMENT

SPONSORED BY WORKING COMMITTEE ON STRENGTH OF COMMITTEE C-1

The Working Committee on Strength completed a comprehensive investigation early in 1954 which indicated that the mechanical mixing of mortars, now required in ASTM Method of Test C 109,[1] develops materially higher strengths with nonair-entraining portland cements than similar mortars prepared by hand mixing.[2] As a result of this study and the new requirement in Method of Test C 109 for mechanical mixing, the Sponsoring Committee on Portland Cement proposed reappraisal of the strength specifications in ASTM Specifications for Portland Cement (C 150)[3] and for Air-Entraining Portland Cement (C 175).[4] The Sponsoring Committee realized that the strength requirements in Specifications C 150 and C 175 might need revision also for reasons other than the effect of the type of mixing on the strength of mortars. The Working Committee on Strength was therefore requested to make an exhaustive study of the level of strengths developed currently by domestic portland cements. This is a condensation of the report of that study which was distributed to Committee C-1 on November 19, 1954.

METHOD OF OBTAINING CURRENT STRENGTH DATA

Sixty-three manufacturers of portland cement and sixteen consumer testing agencies were requested to submit *all* the compressive and tensile strength test data developed in their routine control and testing operations for the first eight months of 1954. The data reported consisted of frequency distributions of the strengths that had been obtained during 1954 (*a*) using the new mechanical-mixing procedure and (*b*) using the hand-mixing procedure. These data were subdivided by types of portland cement and by whether the testing laboratory was a "manufacturers' plant laboratory" or a "consumer testing agency."

In order to assure a maximum response to the request for data, it was believed desirable that the identity of all participants remain anonymous. Therefore, the completed forms were first sent to the National Bureau of Standards where all identification, such as postmarks, was removed and were then forwarded to the chairman of the Working Committee for study. The various identification letters and numerals used in this report were assigned at random as each individual report form was received. Therefore, no key exists which can be used to trace the source or identity of any data. Some multiplant manufacturers submitted combined data from all plants, and some submitted data from individual plants. Some sources submitted tension data entirely separate in terms of chronology from their compression data. The above conditions, combined with the complete anonymity, make possible only the over-all recapitulation of the data received that is given in Table I. This table indicates that a very respectable population of data has been obtained for the major types of portland cement.

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[1] Tentative Method of Test for Compressive Strength of Hydraulic Cement Mortars (Using 2-in. Cube Specimens) (C 109 - 54 T), 1954 Supplement to Book of ASTM Standards, Part 3, p. 16.

[2] See p. 369.

[3] Specifications for Portland Cement (C 150 - 53), 1953 Supplement to Book of ASTM Standards, Part 3, p. 1.

[4] Specifications for Air-Entraining Portland Cement (C 175 - 53), 1952 Book of ASTM Standards, Part 3, p. 6.

Compilation of Data

The original tensile and compressive strength data received from each source were combined into over-all frequency distributions for manual and machine mixing for each type of portland cement. These frequency distributions are presented graphically in Figs. 1 through 6. The population and average of each of these distributions are indicated in the figures. These distributions represent the strength variability and average strength levels of the various domestic cements. No statistical measures of spread or dispersion, such as the range or standard deviation, were calculated for these data because a more realistic estimate of the spread potential can be obtained on the basis of the separate data received from the manufacturing plant laboratories.[5] By this method, the variability due to voluntary production at different strength levels is eliminated. The criterion of especial interest in this study is the potential of control by existing manufacturing methods and test procedures, and this may be developed from the average of the spreads of the individual manufacturer data group.

TABLE I.—NUMBER OF TEST VALUES REPORTED.

	Type of Cement							
	I	IA	II	IIA	III	IIIA	IV	V
Manufacturing Plant Laboratories								
Compressive strength of machine-mixed mortars.........	21 162	4 133	3 173	258	1 002	364	...	12
Compressive strength of hand-mixed mortars..............	13 302	3 467	2 627	357	1 312	581	40	54
Tensile strength (hand-mixed mortars)....................	25 453	4 632	4 432	699	2 391	469	...	69
Consumer Testing Agencies								
Compressive strength of machine-mixed mortars.........	376	106	55	...	18	...	...	...
Compressive strength of hand-mixed mortars..............	4 250	1 280	4 143	...	58	...	80	83
Tensile strength (hand-mixed mortars)....................	5 642	10 661	878	2	514	...	...	...

The average, standard deviation, and coefficient of variation were calculated for the original data from each source. Weighted averages of the average strengths and coefficients of variation were calculated for various subgroupings of the summarized data from each source and are presented in Tables II and III. The weighted average strength for each subgroup in these tabulations represents the current average level of strength of domestic portland cements. The weighted average coefficient of variation provides an estimate of the average (percentage) spread or variation in strengths to be expected from any given plant or manufacturer.

Only the third-order coefficients of variation are given in Tables II and III. The three orders of this coefficient correspond to the commonly referred to 1, 2, and 3σ limits which contain 66, 95, and 99.7 per

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[5] These data were distributed to the members of Committee C-1 with the original report.

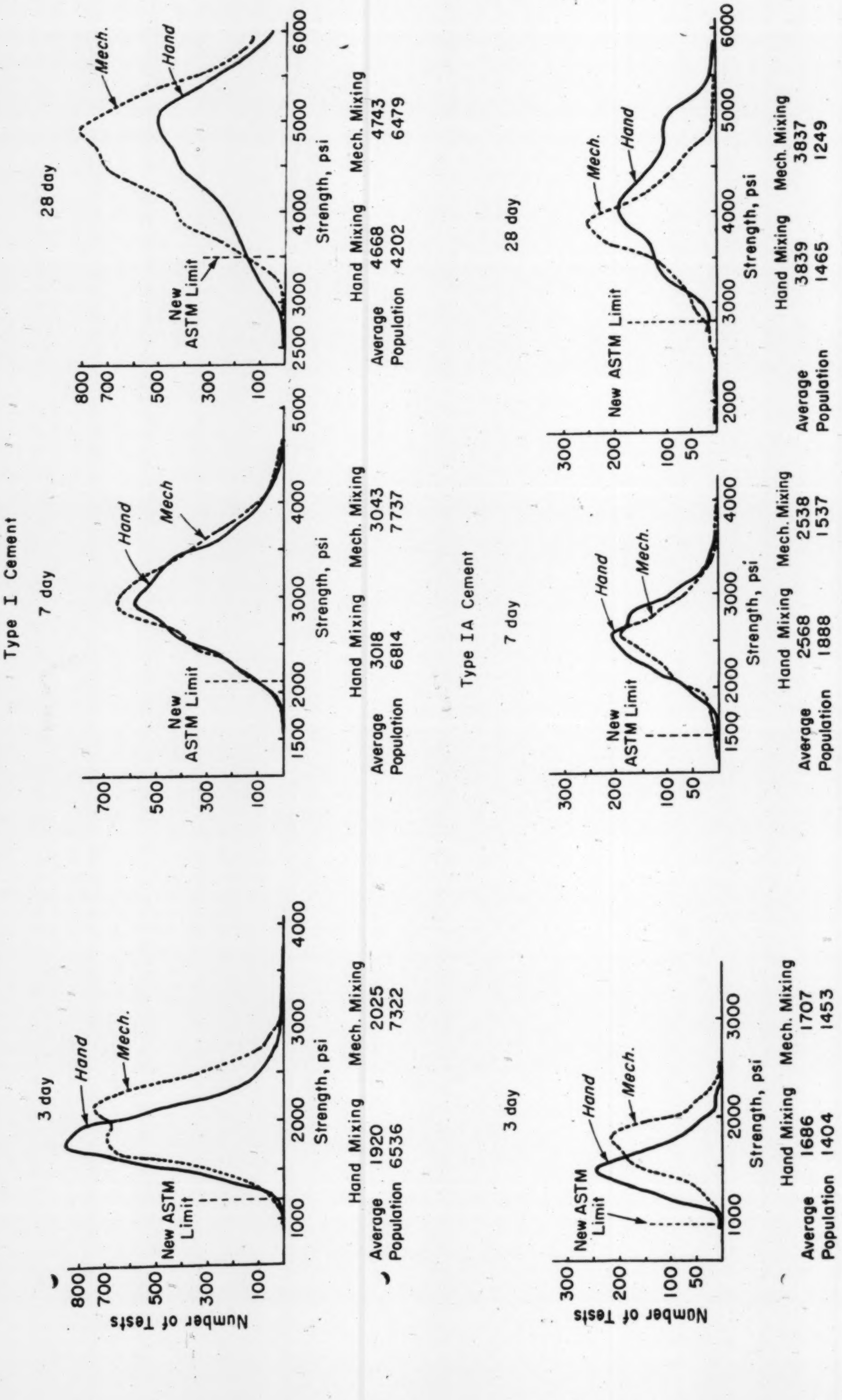
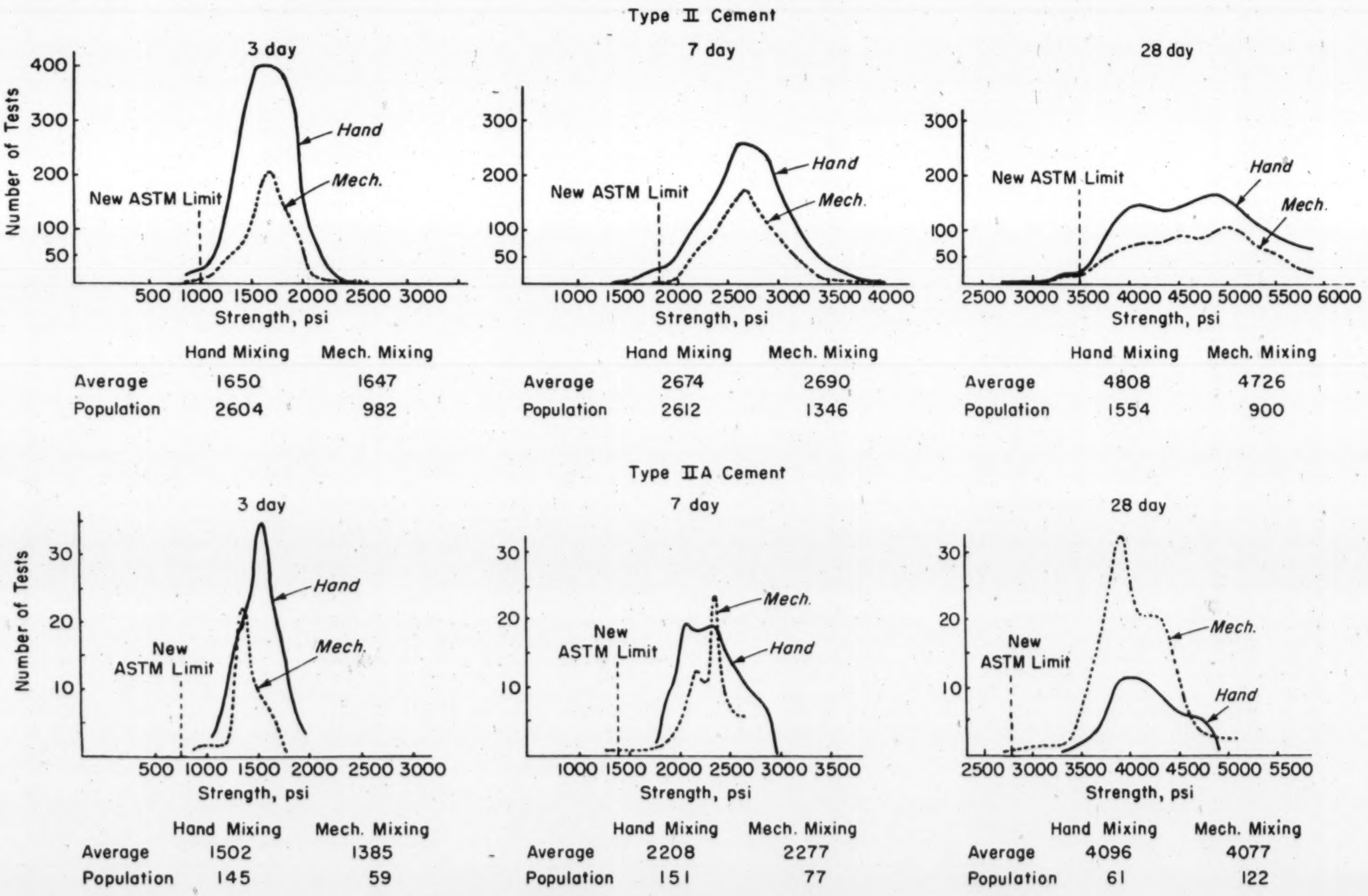


FIG. 1.—Types I and IA Compressive Strength Frequency Distributions.



Type II Cement, 3 day

	Hand Mixing	Mech. Mixing
Average	1650	1647
Population	2604	982

Type II Cement, 7 day

	Hand Mixing	Mech. Mixing
Average	2674	2690
Population	2612	1346

Type II Cement, 28 day

	Hand Mixing	Mech. Mixing
Average	4808	4726
Population	1554	900

Type IIA Cement, 3 day

	Hand Mixing	Mech. Mixing
Average	1502	1385
Population	145	59

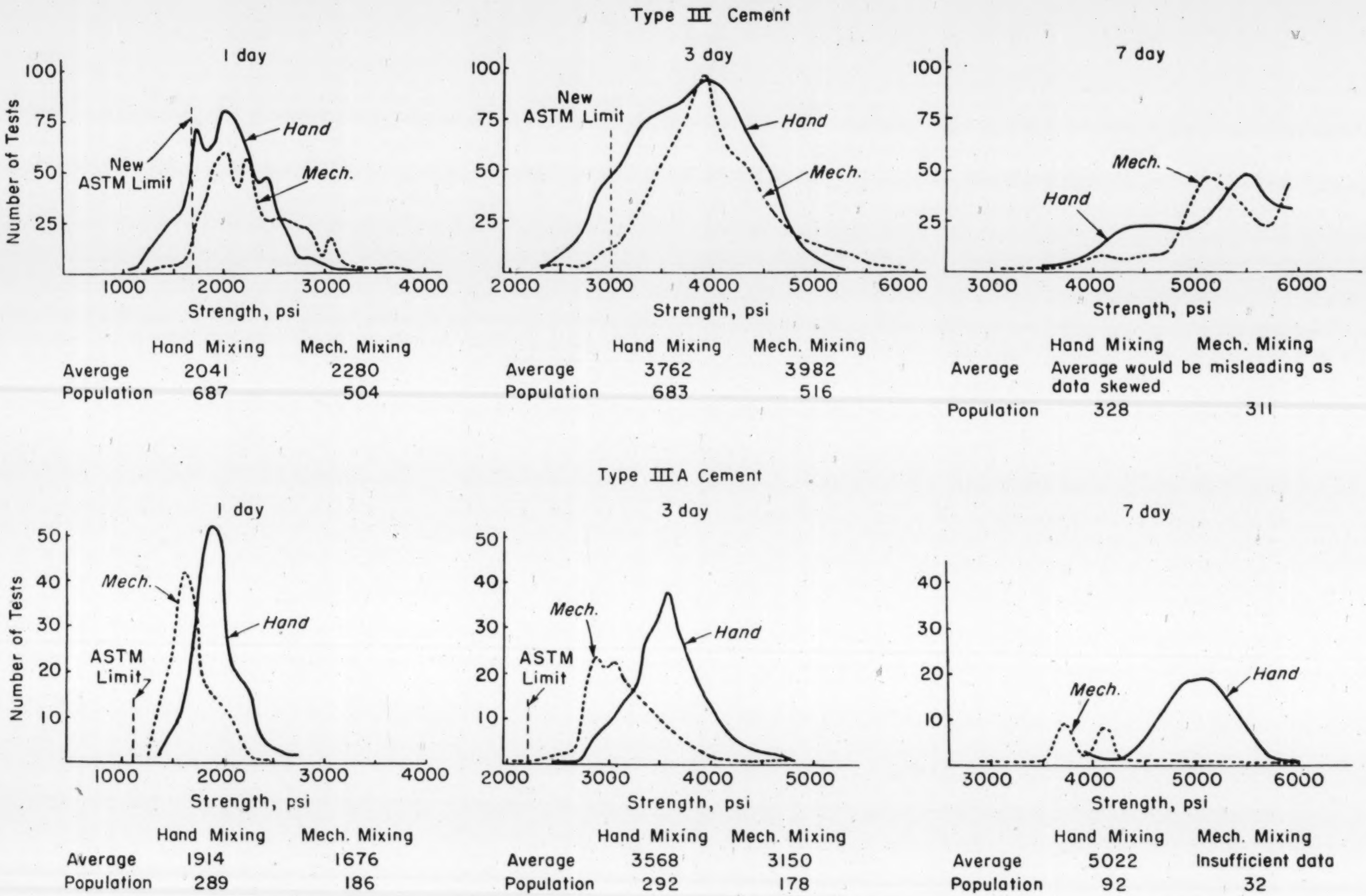
Type IIA Cement, 7 day

	Hand Mixing	Mech. Mixing
Average	2208	2277
Population	151	77

Type IIA Cement, 28 day

	Hand Mixing	Mech. Mixing
Average	4096	4077
Population	61	122

FIG. 2.—Types II and IIA Compressive Strength Frequency Distributions.



Type III Cement, 1 day

	Hand Mixing	Mech. Mixing
Average	2041	2280
Population	687	504

Type III Cement, 3 day

	Hand Mixing	Mech. Mixing
Average	3762	3982
Population	683	516

Type III Cement, 7 day

	Hand Mixing	Mech. Mixing
Average	Average would be misleading as data skewed	
Population	328	311

Type IIIA Cement, 1 day

	Hand Mixing	Mech. Mixing
Average	1914	1676
Population	289	186

Type IIIA Cement, 3 day

	Hand Mixing	Mech. Mixing
Average	3568	3150
Population	292	178

Type IIIA Cement, 7 day

	Hand Mixing	Mech. Mixing
Average	5022	Insufficient data
Population	92	32

FIG. 3.—Types III and IIIA Compressive Strength Frequency Distributions.

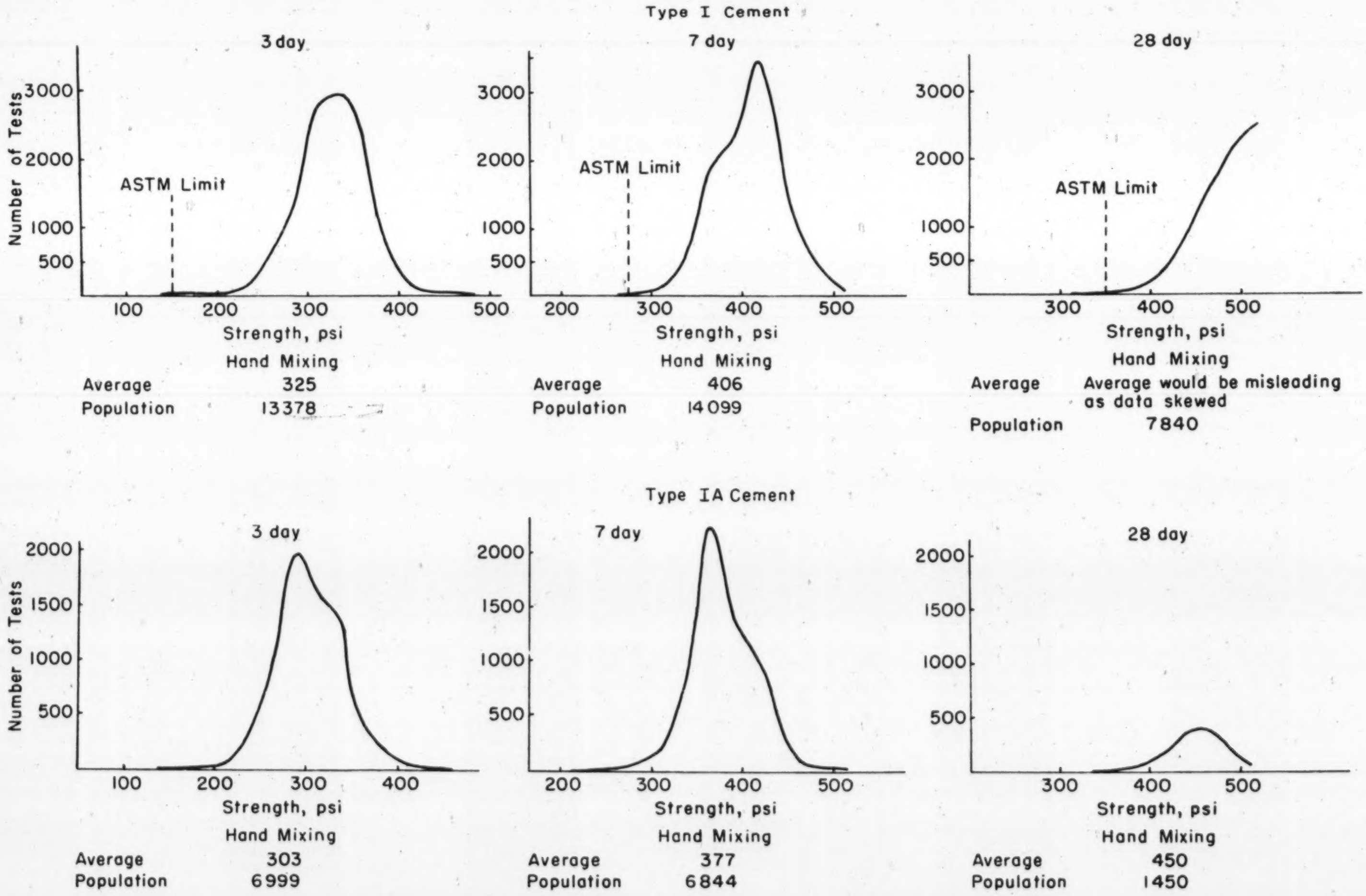


FIG. 4.—Types I and IA Tensile Strength Frequency Distributions.

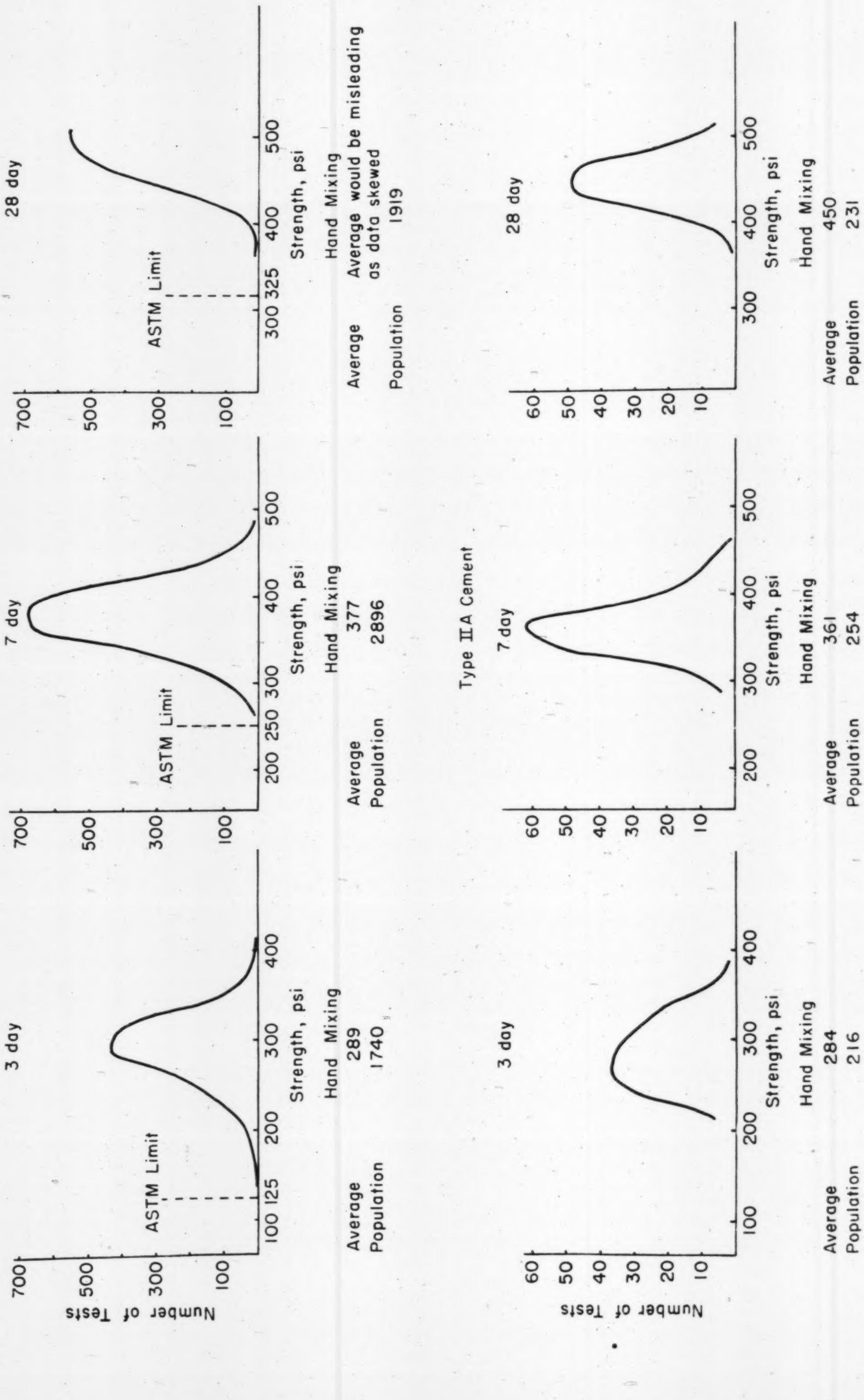


FIG. 5.—Types II and IIA Tensile Strength Frequency Distributions.

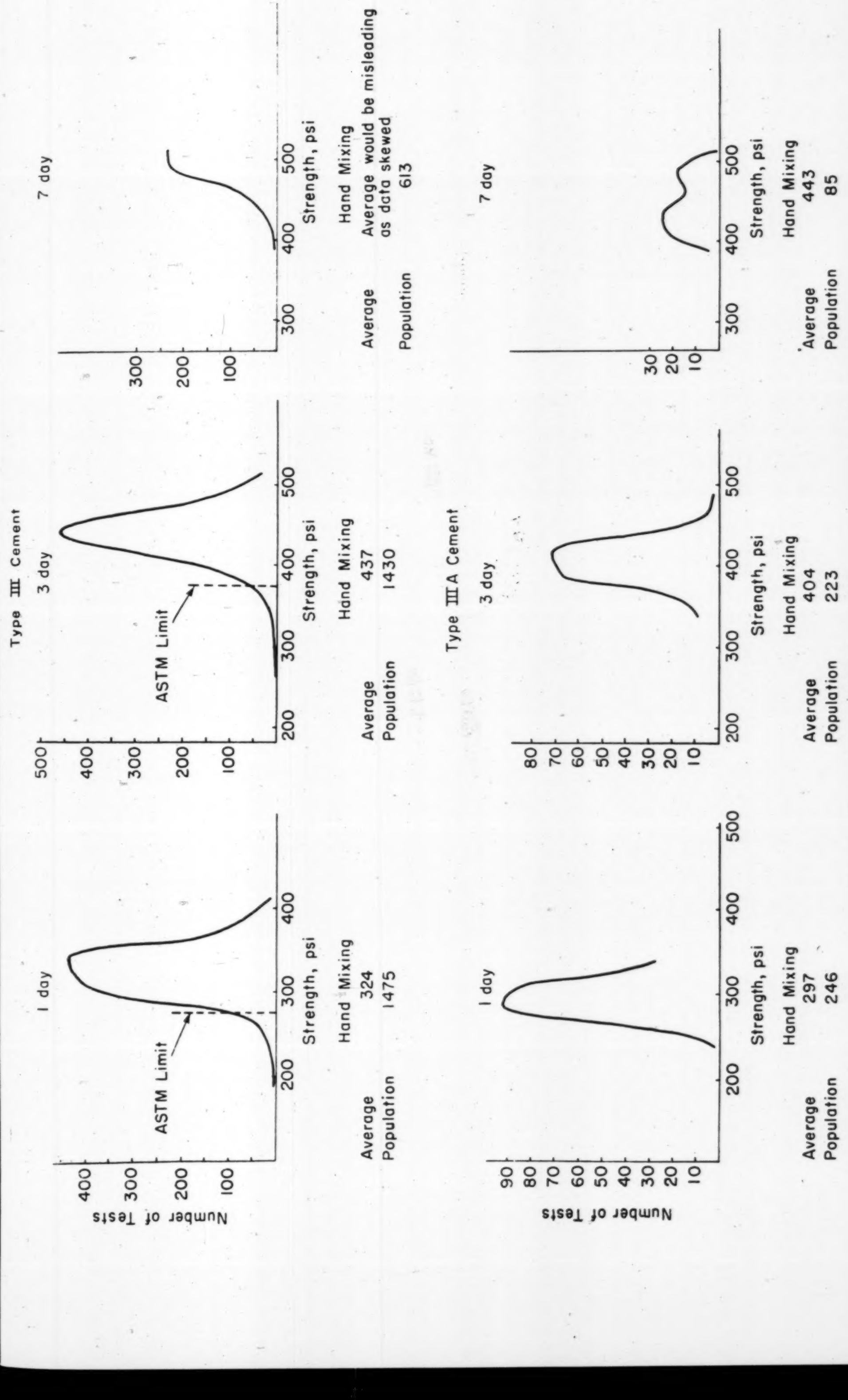


FIG. 6.—Types III and IIIA Tensile Strength Frequency Distributions.

cent, respectively, of the values in a distribution. As the coefficient of variation represents the *percentage* spread, the absolute spread in pounds per square inch can be obtained by multiplying the average strength by the coefficient of variation. When the third-order coefficient is used, 99.7 per cent of the data in the distribution will be within the limits obtained by applying the plus and minus values of the absolute spread in pounds per square inch to the average strength. Since the variations are based on *averaged* data from each individual source, extreme variations are not brought out, and it should be remembered that the extreme spread of the data is greater than indicated. For this reason the limits based on the third-order coefficient of variation are deemed appropriate.

TABLE II.—PARAMETERS OF COMPRESSIVE STRENGTH.

Type of Cement	1 Day			3 Days			7 Days			28 Days		
	N[a]	$\overline{X}$[b]	V[c]	N	$\overline{X}$	V	N	$\overline{X}$	V	N	$\overline{X}$	V
MANUFACTURING PLANT DATA—MACHINE-MIXED MORTARS												
I	...	...	...	7133	2025	31.8	7550	3064	28.5	6479	4725	24.6
IA	...	...	...	1399	1697	37.2	1485	2522	34.2	1249	3808	27.3
II	...	...	...	952	1747	32.7	1321	2687	29.4	900	4724	24.0
IIA	...	...	...	59	1389	[d]	77	2277	18.0	122	4053	27.3
III	495	2291	31.8	507	3985	25.8	...	...	...	...	...	...
IIIA	186	1676	27.6	178	3155	21.3	...	...	...	...	...	...
V	...	...	...	6	1683	[d]	6	2450	[d]	...	...	...
MANUFACTURING PLANT DATA—HAND-MIXED MORTARS												
I	...	...	...	4463	1912	31.5	4714	3007	27.9	4125	4678	23.4
IA	...	...	...	1228	1688	37.8	1225	2584	34.5	1014	3911	31.2
II	...	...	...	923	1617	32.7	911	2587	29.4	793	4541	23.4
IIA	...	...	...	145	1502	28.5	151	2408	25.2	61	4257	21.0
III	658	2052	33.9	654	3808	22.8	...	...	...	...	...	...
IIIA	289	1950	19.8	292	3564	13.2	...	...	...	...	...	...
IV	...	...	...	...	...	...	20	1400	[d]	20	4010	[d]
V	...	...	...	...	...	...	27	2268	[d]	24	3366	[d]
CONSUMER TEST LABORATORY DATA—MACHINE-MIXED MORTARS												
I	...	...	...	189	1958	36.9	187	3122	36.0	...	...	...
IA	...	...	...	54	1909	25.5	52	2883	23.7	...	...	...
II	...	...	...	30	1673	36.0	25	2814	[d]	...	...	...
III	9	2106	[d]	9	3661	[d]	...	...	...	...	...	...
CONSUMER TEST LABORATORY DATA—HAND-MIXED MORTARS												
I	...	...	...	2073	1896	50.1	2100	3044	44.7	77	4874	[d]
IA	...	...	...	176	1702	40.2	663	2527	32.1	441	4068	38.4
II	...	...	...	1681	1663	48.6	1701	2718	45.6	761	4908	46.5
III	29	2060	[d]	29	3936	[d]	7	4671	[d]	...	...	...
IV	...	...	...	...	...	...	40	1768	25.8	40	4380	44.1
V	...	...	...	3	1783	[d]	41	2299	48.6	39	4080	57.6

[a] N = number of tests.
[b] $\overline{X}$ = average, psi.
[c] V = third-order coefficient of variation, per cent.
[d] Insufficient data.

TABLE III.—PARAMETERS OF TENSILE STRENGTH—HAND-MIXED MORTARS.

Type of Cement	1 Day			3 Days			7 Days			28 Days		
	N[a]	$\bar{X}$[b]	V[c]	N	$\bar{X}$	V	N	$\bar{X}$	V	N	$\bar{X}$	V
MANUFACTURING PLANT DATA												
I......	...	...	...	10 768	325	23.4	11 307	405	18.6	3378	457	16.2
IA.....	...	...	...	1 569	307	28.8	1 613	381	23.7	1450	446	18.0
II......	...	...	...	1 538	295	30.6	2 320	378	22.8	574	460	18.6
IIA.....	...	...	...	215	289	32.1	253	365	21.3	231	452	17.1
III......	1216	328	22.2	1 175	436	17.7	...	...	...	...	...	...
IIIA.....	246	297	18.3	223	405	14.1	...	...	...	...	...	...
V......	...	...	...	27	257	[d]	33	342	[d]	6	495	[d]
CONSUMER TESTING LABORATORY												
I......	...	...	...	2 610	325	31.2	2 792	403	24.0	240	452	21.9
IA.....	...	...	...	5 430	302	34.8	5 231	379	27.9	...	...	...
II......	...	...	...	202	260	56.1	576	371	27.3	100	437	27.0
IIA.....	...	...	...	1	287	[d]	1	375	[d]	...	...	...
III......	259	304	26.4	255	431	25.2	...	...	...	...	...	...

[a] N = number of tests.

[b] $\bar{X}$ = average, psi.

[c] V = third-order coefficient of variation, per cent.

[d] Insufficient data.

TABLE IV.—COMPARISON OF DISTRIBUTION PARAMETERS FOR HAND- AND MACHINE-MIXED COMPRESSIVE STRENGTHS (MANUFACTURING PLANT DATA).

Type of Cement	Test Age	Machine-Mixed Mortars					Hand-Mixed Mortars				
		Average Strength Level, psi	Average Coefficient of Variation (Third-Order)	One Half of Distribution Spread[a]	Average Lower Limit[b]	Average Upper Limit[b]	Average Strength Level, psi	Average Coefficient of Variation (Third-Order)	One Half of Distribution Spread[a]	Average Lower Limit[b]	Average Upper Limit[b]
I.......	3 days	2025	31.8	644	1381	2669	1912	31.5	602	1310	2514
I.......	7 days	3064	28.5	873	2191	3937	3007	27.9	839	2168	3846
I.......	28 days	4725	24.6	1162	3563	5887	4678	23.4	1095	3583	5773
IA.....	3 days	1697	37.2	631	1066	2328	1688	37.8	638	1050	2326
IA.....	7 days	2522	34.2	863	1659	3385	2584	34.5	891	1693	3475
IA.....	28 days	3808	27.3	1040	2768	4848	3911	31.2	1220	2691	5131
II.......	3 days	1747	32.7	571	1176	2318	1617	32.7	529	1088	2146
II.......	7 days	2687	29.4	790	1897	3477	2587	29.4	761	1826	3348
II.......	28 days	4724	24.0	1134	3590	5858	4541	23.4	1063	3478	5604
III.......	1 day	2291	31.8	729	1562	3020	2052	33.9	696	1356	2748
III.......	3 days	3985	25.8	1028	2957	5013	3808	22.8	868	2940	4676

[a] One half of the distribution spread is obtained by multiplying the average strength by the third-order coefficient of variation.

[b] These limits are obtained by adding or subtracting one half of the distribution spread from the average strength. The spread between these limits represents the average spread obtained by the present manufacturing facilities.

RESULTS

The average strengths and third-order coefficients of variation obtained from Table II for manufacturing plant data only have been summarized in Table IV. For each type of cement and each test age, the spread and limits based on the third-order coefficient of variation have also been tabulated. Data for types IIA, IIIA, IV, and V cements were not included due to the limited population of test results received for those types.

Table IV also contains a comparison of hand- and machine-mixed compressive strength results. These data indicate little, if any, differences in the strength level developed by the two types of mixing. This is in contrast with the finding of the previous investigation by this Working Committee[2] which indicated that significantly higher (10 to 15 per cent) compressive strengths were obtained for machine mixing of nonair-entraining mortars. It should be pointed out, however, that the data for hand and machine mixing in this current survey probably were not obtained from the same cements—that is, it is very probable that the hand-mixed data were developed early in 1954, prior to delivery of the mechanical mixers, whereas the machine-mixed data are from a later period after cessation of hand mixing. The basic comparisons of influence of mixing method given in the previous report are more directly valid.

Respectfully submitted on behalf of the Working Committee on Strength,

C. E. WUERPEL,
Chairman.

MEMBERS:
R. F. BLANKS
C. L. DAVIS
W. T. MORAN
M. A. SWAYZE
BAILEY TREMPER
T. M. WHITESIDE

REPORT OF COMMITTEE C-3

ON

CHEMICAL-RESISTANT MORTARS*

Committee C-3 on Chemical-Resistant Mortars held two meetings during the year: on June 14, 1954, in Chicago, Ill., and on September 24, 1954, in Watertown, N. Y.

The membership of the committee consists of 28 members, of whom 9 are classified as producers, 7 as consumers, 9 as general interest members, and 3 as consulting members.

ADOPTION OF TENTATIVES AS STANDARD WITH REVISION

Committee C-3 recommends that Notes 1 and 2 be deleted from the following three tentative methods and that the methods then be approved for reference to letter ballot of the Society for adoption as standard:

Tentative Methods of Test for:

Compressive Strength of Resin Type Chemical Resistant Mortars (**C 306 – 53 T**),[1]
Tensile Strength of Resin Type Chemical Resistant Mortars (**C 307 – 53 T**),[1] and
Working and Setting Times of Resin Type Chemical Resistant Mortars (**C 308 – 53 T**).[1]

The recommendations appearing in this report have been submitted to letter ballot of the committee, the results of which will be reported at the Annual Meeting.[2]

ACTIVITIES OF SUBCOMMITTEES

Subcommittee II on Silicate Mortars (R. F. Strigle, chairman) has continued its work on the chemically setting type of silicate mortars, and the proposed methods under consideration for determining tensile and compressive strength were quantitatively evaluated by testing three commercial silicate mortars in three laboratories. Due to the nature of the variations of the resulting data, it was decided that the tests should be repeated. A method is also being studied for determining the absorption or porosity of silicate mortars.

Subcommittee IX on Chemical Resistance (R. H. Steiner, chairman) has continued work on the chemical resistance of resin mortars, and it is hoped agreement can be reached on a proposed method during 1955.

Subcommittee X on Special Properties (W. H. Burton, chairman) was organized on September 24, 1954, to develop a list of the more important properties for which test methods on chemical-resistant mortars are desired and to recommend an order of study. This subcommittee will issue a report to Committee C-3 prior to the Annual Meeting of the Society.

This report has been submitted to letter ballot of the committee, which consists of 28 members; 27 members returned their ballots, all of whom have voted affirmatively.

Respectfully submitted on behalf of the committee,

BEAUMONT THOMAS,
Chairman.

E. A. REINECK,
Secretary.

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* Presented at the Fifty-eighth Annual Meeting of the Society, June 26–July 1, 1955.

[1] 1953 Supplement to Book of ASTM Standards, Part 3

[2] The letter ballot vote on these recommendations was favorable; the results of the vote are on record at ASTM Headquarters.

REPORT OF COMMITTEE C-7

ON

LIME*

Committee C-7 on Lime held two meetings during the past year: the first at Chicago, Ill., on June 17, 1954, at the time of the Annual Meeting of the Society, and the second at Cincinnati, Ohio, on February 3, 1955, during ASTM Committee Week.

The committee consists of 52 members, of whom 22 are classified as producers, 7 as consumers, and 23 as general interest members.

RECOMMENDATIONS ACCEPTED BY THE ADMINISTRATIVE COMMITTEE ON STANDARDS

Subsequent to the 1954 Annual Meeting, Committee C-7, jointly with Committee C-11 on Gypsum, presented to the Society through the Administrative Committee on Standards the recommendation for the revision of Tentative Specifications for Inorganic Aggregates for Use in Interior Plaster (**C 35 – 53 T**). This recommendation was accepted by the Standards Committee on December 22, 1954, and the revised specifications appear in the 1954 Supplement to Book of ASTM Standards, Part 3.

ADOPTION OF TENTATIVE REVISIONS AS STANDARD

The committee recommends that the tentative revisions[1] of Sections 2 to 7 and Section 21 of the Standard Specifications for Hydraulic Hydrated Lime for Structural Purposes (**C 141 – 42**)[2] be approved for reference to letter ballot of the Society for adoption as standard.

REAPPROVAL OF STANDARDS

The committee recommends reapproval of the following standards:

Standard Specifications for:

Quicklime and Hydrated Lime for Cooking of Rags in Paper Manufacture (**C 45 – 25**),
Quicklime for Sulfite Pulp Manufacture (**C 46 – 27**),
Hydrated Lime for Varnish Manufacture (**C 47 – 27**), and
Quicklime and Hydrated Lime for Silica Brick Manufacture (**C 49 – 42**).

TENTATIVES CONTINUED WITHOUT REVISION

The committee recommends that the Tentative Specifications for Quicklime and Hydrated Lime for Water Treatment (**C 53 – 52 T**) be continued without revision.

The recommendations in this report have been submitted to letter ballot of the committee, the results of which will be reported at the Annual Meeting.[3]

SUBCOMMITTEE ACTIVITIES

A new Subcommittee on Pozzolans has been formed under the chairmanship of N. C. Rockwood to prepare specifications for pozzolans in their various uses with lime.

Subcommittee III on Lime for the

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* **Presented at the Fifty-eighth Annual Meeting of the Society, June 26–July 1, 1955.**

[1] **1953 Supplement to Book of ASTM Standards, Part 3.**

[2] **1952 Book of ASTM Standards, Part 3.**

[3] **The letter ballot vote on these recommendations was favorable; the results of the vote are on record at ASTM Headquarters.**

Chemical Industries (R. W. McAllister, chairman).—The work of this subcommittee has been largely confined to the development of specifications covering the use of lime in silica brick and glass manufacture.

Subcommittee V on Methods of Test of Lime and Lime Products (D. G. Hamme, chairman) has developed two proposed tests on lime neutralization which are under consideration in the committee.

Subcommittee IX on Research (W. C. Voss, chairman) has a testing program under way in determining soundness characteristics of limes in a proposed autoclave testing procedure.

This report has been submitted to letter ballot of the committee, which consists of 52 members; 39 members returned their ballots, of whom 38 have voted affirmatively and 0 negatively.

Respectfully submitted on behalf of the committee,

JAMES A. MURRAY,
Chairman.

ROBERT S. BOYNTON,
Secretary.

REPORT OF COMMITTEE C-8

ON

REFRACTORIES*

Committee C-8 on Refractories held two meetings during the year: the eighty-sixth meeting at Bedford Springs, Pa., on September 16, 1954, and the eighty-seventh meeting at Cincinnati, Ohio, on February 2, 1955.

At the present time there are 42 members on the committee, of whom 21 are classified as producers, 13 as consumers, and 8 as general interest members.

RECOMMENDATIONS ACCEPTED BY THE ADMINISTRATIVE COMMITTEE ON STANDARDS

Subsequent to the 1954 Annual Meeting, Committee C-8 presented to the Society through the Administrative Committee on Standards a Tentative Method of Test for Bulk Density of Granular Refractory Materials (**C 357 – 55 T**). The method was accepted by the Standards Committee on March 23, 1955.

REVISIONS OF TENTATIVES

The committee recommends that the following tentative methods be revised as appended hereto:[1]

Method of Test for:

Modulus of Rupture of Castable Refractories (**C 268 – 51 T**),[2] and

Permanent Linear Change on Firing of Castable Refractories (**C 269 – 51 T**).[2]

TENTATIVE REVISIONS OF STANDARDS

The committee recommends for publication as tentative revisions of the following standards as indicated:

Standard Method of Test for Pyrometric Cone Equivalent (P.C.E.) of Refractory Materials (C 24 – 46):[2]

Section 2(a).—Delete the fourth sentence and add the following note:

NOTE.—Care shall be taken during the crushing and grinding of the sample to prevent the introduction of magnetic material.

Section 4.—Change the first sentence to read:

Both test and P.C.E. cones shall be mounted on plaques of refractory material of such a composition as will not affect the fusibility of the cones.

Change the second sentence to read:

Both test and P.C.E. cones shall be mounted with the base so embedded that the length of the sloping face of the cone above the plaque shall be $\frac{15}{16}$ in. and the face of the cone (about which bending takes place) shall be inclined at an angle of 82 deg with the horizontal.

In the 11th and 14th lines, add "(P.C.E.)" after the words "Pyrometric Cones."

Section 5(a).—Change to read as follows:

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* Presented at the Fifty-eighth Annual Meeting of the Society, June 26–July 1, 1955.

[1] The revised tentatives appear in the 1955 Book of ASTM Standards, Part 3.

[2] 1952 Book of ASTM Standards, Part 3.

5. (*a*) The heating shall be carried out in a suitable furnace, operating with an oxidizing atmosphere, at rates to conform to the following requirements:

A. For P.C.E. tests expected to have an end point of P.C.E. cone 12 or above but not exceeding cone 26.

Cone Interval	Time Interval	Cumulative Time
Cold test furnace to:		
Cone 12.........	45 min	45 min
Cone 13.........	5 min	50 min
Cone 14.........	19 min	1 hr 9 min
Cone 15.........	13 min	1 hr 22 min
Cone 16.........	24 min	1 hr 46 min
Cone 17.........	9 min	1 hr 55 min
Cone 18.........	4 min	1 hr 59 min
Cone 19.........	8 min	2 hr 7 min
Cone 20.........	9 min	2 hr 16 min
Cone 23.........	16 min	2 hr 32 min
Cone 26.........	7 min	2 hr 39 min

B. For P.C.E. tests expected to have an end point above cone 26.

Cone Interval	Time Interval	Cumulative Time
Cold Test Furnace to:		
Cone 20.........	45 min	45 min
Cone 23.........	16 min	1 hr 1 min
Cone 26.........	7 min	1 hr 8 min
Cone 27.........	7 min	1 hr 15 min
Cone 29.........	8 min	1 hr 23 min
Cone 31.........	10 min	1 hr 33 min
Cone 31½.......	6 min	1 hr 39 min
Cone 32.........	7 min	1 hr 46 min
Cone 32½.......	3 min	1 hr 49 min
Cone 33.........	7 min	1 hr 56 min
Cone 34.........	9 min	2 hr 5 min
Cone 35.........	9 min	2 hr 14 min
Cone 36.........	7 min	2 hr 21 min
Cone 37.........	7 min	2 hr 28 min

NOTE 1.—The heating rate through the cone series in both tables is at 150 C per hr. (270 F).

NOTE 2.—Following a test run, the cone pat may be removed at 1830 F (1000 C) and a new pat may be put in without cooling the furnace to below red heat. The time interval to bring the furnace using Table A up to cone 12 shall be not less than 20 min, and using Table B the time interval up to cone 20 shall be not less than 25 min.

Appendix.—Change to read as follows:

APPENDIX

The approximate temperature equivalents corresponding to the end points of those Standard Pyrometric Cones (P.C.E.) that are used in connection with refractory testing are as follows:

Cone No.	End Point Deg. F	End Point Deg. C	Cone No.	End Point Deg. F	End Point Deg. C
12.....	2439	1337	31.....	3061	1683
13.....	2460	1349	31½...	3090	1699
14.....	2548	1398	32.....	3123	1717
15.....	2606	1430	32½...	3135	1724
16.....	2716	1491	33.....	3169	1743
17.....	2754	1512	34.....	3205	1763
18.....	2772	1522	35.....	3245	1785
19.....	2806	1541	36.....	3279	1804
20.....	2847	1564	37.....	3308	1820
23.....	2921	1605	38.....	3335	1835[a]
26.....	2950	1621	39.....	3389	1865[a]
27.....	2984	1640	40.....	3425	1885[a]
28.....	2995	1646	41.....	3578	1970[a]
29.....	3018	1659	42.....	3659	2015[a]
30.....	3029	1665			

[a] Fairchild and Peters, "Characteristics of Pyrometric Cones," Journal, American Ceramic Society, Vol. 9, No. 11, p. 700, November 1926.

Heating rate: Cones 12 to 37, incl.: 150 C per hr. (270 F per hr.); Cone 38:100 C per hr. (180 F per hr.); Cones 39 to 42, incl.: 600 C per hr. (1080 F per hr.)

P.C.E. cones 28 and 30 are shown above as information only. They are manufactured and used in special applications in industry but are not used in the P.C.E. test as specified by Method C 24.

All temperatures, except for cones 38 to 42, inclusive, were determined by H. P. Beerman, Research Associate of the Edward Orton Jr. Ceramic Foundation at the National Bureau of Standards. These temperatures apply satisfactorily for all the conditions of this test method, but do not apply to the conditions of commercial firing of kilns and use of refractory materials.

Temperature values were determined in degrees Centigrade. The Fahrenheit temperature values were calculated.

Standard Definitions of Terms Relating to Refractories (C 71 – 53):[3]

Following the definition of "Magnesite-Chrome Brick," add the following new definition: *Nine Inch Series Brick.*—A group of plane-surfaced brick shapes having over-all nominal dimensions not greater than 9 by 4½ by 3 in.

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[3] 1953 Supplement to Book of ASTM Standards, Part 3.

ADOPTION OF TENTATIVE AS STANDARD WITHOUT REVISION

The committee recommends that the Tentative Classification of Single- and Double-Screened Ground Refractory Material (**C 316 – 53 T**)[3] be approved for reference to letter ballot of the Society for adoption as standard without revision.

ADOPTION OF TENTATIVE REVISIONS AS STANDARD

The committee recommends that tentative revisions of the following standards be approved for reference to letter ballot of the Society for adoption as standard:

Standard Definitions of Terms Relating to Refractories (C 71 – 53):[3] Tentative revision[4] of Refractories, n., and Refractory, adj., issued June, 1952, and modified June, 1953; Mullite Refractories, and Silicon Carbide Refractories, issued June, 1954.

Standard Methods of Test for Cold Crushing Strength and Modulus of Rupture of Refractory Brick and Shapes (C 133 – 49):[2] Tentative revision[3] issued June, 1953, now to be added to Section 9(*b*) instead of Section 8.

Standard Specifications for Fireclay-Base Castable Refractories for Boiler Furnaces and Incinerators (C 213 – 51):[2] Tentative revision[4] issued June, 1954, relating to Sections 2, 3, 4, 5, 9, and Table I.

REAPPROVAL OF STANDARDS

The committee recommends that the following standards be reapproved without change:

Standard Classification for:

Insulating Fire Brick (C 155 – 47),

Standards Methods of Test for:

Refractory Brick Under Load at High Temperatures (C 16 – 49),

Sieve Analysis and Water Content of Refractory Materials (C 92 – 46),

Warpage of Refractory Brick and Tile (C 154 – 41),

Combined Drying and Firing Shrinkage of Fireclay Plastic Refractories (C 179 – 46),

Panel Spalling Test for Fireclay Plastic Refractories (C 180 – 52),

Workability Index of Fireclay Plastic Refractories (C 181 – 47),

Bonding Strength of Air-Setting Refractory Mortar (Wet Type) (C 198 – 47), and

Refractoriness of Air-Setting Refractory Mortar (Wet Type) (C 199 – 47).

The recommendations in this report have been submitted to letter ballot of the committee, the results of which will be reported at the Annual Meeting.[5]

EDITORIAL REVISIONS

The committee recommends editorial revisions of the following standards as indicated:

Standard Method of Test for Pyrometric Cone Equivalent (P.C.E.) of Refractory Materials (C 24 – 46):

Section 1.—In line 6 following "Standard Pyrometric Cones" add "(P.C.E.)."

Section 6.—In line 7, add "(P.C.E.)" after the word "Equivalent."

In the first sentence of the Note, add "(P.C.E.)" after the word "Cones."

Standard Specifications for Ground Fire Clay as a Mortar for Laying-up Fireclay Brick (C 105 – 47):

Section 5(a).—Change the requirement as to Pyrometric Cone Equivalent for High Duty Class from "28" to "27–29."

Standard Specifications for Refractories for Malleable Iron Furnaces with Removable Bungs, and for Annealing Ovens (C 63 – 51):

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[4] 1954 Supplement to Book of ASTM Standards, Part 3.

[5] The letter ballot vote on these recommendations was favorable; the results of the vote are on record at ASTM Headquarters.

Section 7(a).—Change "9-in. Series" to read "9 by $4\frac{1}{2}$ by $2\frac{1}{2}$-in. or 3-in." Delete Note 1.

Section 7(b).—Change "Note 2" to read "Note 1."

Standard Specifications for Refractories for Heavy Duty Stationary Boiler Service (C 64 – 51):

Section 5.—Make the same changes as in Section 7 of Specifications C 63 – 51 above.

Standard Specifications for Refractories for Incinerators (C 106 – 51):

Section 4.—Make the same changes as in Section 7 of Specifications C 63 – 51 above.

Standard Specifications for Refractories for Moderate Duty Stationary Boiler Service (C 153 – 51):

Section 4.—Make the same changes as in Section 7 of Specifications C 63 – 51 above.

ACTIVITIES OF SUBCOMMITTEES

Subcommittee I on Industrial Survey (R. P. Stevens, chairman) has one new survey partly finished, five awaiting an author.

Subcommittee II on Research (S. M. Swain, chairman) has supplied for publication six descriptions of research problems in refractories and is at work on three more.

Subcommittee III on Tests (S. M. Phelps, chairman):

Section (A) on Load (A. J. Metzger, chairman) has reported on a miniature hot load test and is at work on the correlation of modulus of rupture of straight and arch brick and on temperature distribution in the standard hot load test.

Section (C) on Temperature (J. L. Carruthers, chairman) has enlarged the scope of the P.C.E. test to include cones Nos. 12 to 20 and has made changes in the series above No. 26 that are included in the tentative revisions of Method C 24. Cones 28 and 30 have been deleted from the test series and a cone $31\frac{1}{2}$ has been added. The new temperature equivalents of cones 12 to 37 determined at the National Bureau of Standards have been reported to the Orton Foundation and will be published in the current year.

Section (E) on Chemical Analysis (H. A. Heiligman, chairman) has assembled new laboratory data for a test method for alkalies based on the flame photometer. The section is cooperating with Committee C-1 on analytical methods for portland cement and with Committee E-2 on emission spectroscopy. It reports progress on a test method for hydration of magnesia refractories, and on new standard samples for silica brick lower in alumina than the present Bureau of Standards samples.

Section (G) on Porosity and Permanent Volume Change (S. M. Swain, chairman) reports no progress in two attempts to improve the recently adopted tentative method for bulk density of granular materials.

Section (H) on Mortars and Plastic and Castable Refractories (W. O. Brandt, chairman) is considering methods of test for an elusive property known as "consistency."

Subcommittee IV on Heat Transfer (C. L. Norton, Jr., chairman) reports that ten laboratories have the ASTM equipment for thermal conductivity of refractories and three others are assembling it. Progress is reported on a cooperative study of the conductivity of silicon carbide brick with the Special Refractories Assn.

Subcommittee VI on Nomenclature (W. S. Debenham, chairman) has supplied a standard definition of "9-in. Series Brick."

Subcommittee VII on Specifications (J. D. Sullivan, chairman), in addition to the recommendations previously mentioned, has transmitted comments on three Federal Specifications to the General Services Administration and reports that these specifications are adhering fairly closely to ASTM standards.

Subcommittee IX on Classifications (A. H. Couch, chairman) has prepared a new classification of fireclay brick which is to be distributed to the refractories industry for comment. The suggested classification is appended hereto[6] as information. A test program has been started to obtain data for the classification of silica brick.

Subcommittee XI on Special Refractories (H. C. Fisher, chairman) reports that no proposals have been received from the Special Refractories Assn. as to the classification of mullite refractories and silicon carbide refractories, terminology, or load tests, all of which subjects appear to be in need of standardization. Committee C-8 has adopted two definitions, and certain analytical methods are awaiting review by Section (E) of Subcommittee III.

Subcommittee XII on Carbon Refractories (E. B. Snyder, chairman) has prepared programs for the study of test methods for reheat change, permeability to gases, thermal conductivity, disintegration by carbon monoxide, rates of oxidation, and attack by alkalies. Some data have already been assembled on these subjects. The cooperation of the Crucible Manufacturers' Assn. has been solicited.

Subcommittee XV on Basic Granular Refractories (J. J. Hazel, chairman) has prepared tentative classifications for three types of refractory dolomite: raw, calcined, and dead burned. Tentative physical and chemical test methods for refractory dolomite are under discussion with the Dolomite Refractories Assn.

An ad hoc Subcommittee on Specifications for Lime for the Manufacture of Silica Brick has been appointed, consisting of L. J. Trostel (chairman), R. E. Birch, and S. M. Swain.

This report has been submitted to letter ballot of the committee, which consists of 42 members; 40 members returned their ballots, all of whom have voted affirmatively.

Respectfully submitted on behalf of the committee,

R. B. SOSMAN,
Chairman.

W. R. KERR,
Secretary.

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[6] See p. 397.

APPENDIX

SUGGESTED CLASSIFICATION OF FIRECLAY REFRACTORY BRICK[1]

SUBMITTED BY C-8 SUBCOMMITTEE IX

Scope

1. This classification pertains to machine-made fireclay refractory brick, and its purpose is to set forth the various classes and types of these materials in accordance with their normal and characteristic properties which are important in their use.

Classes and the Properties Required

2. Fireclay retractory brick are classified under the following six headings: Super Duty, High Duty, Semi-Silica, Medium Duty, Low Duty, and Alumina-Diaspore. The Super Duty, High Duty, and Alumina-Diaspore classes are divided further into three types under each class. The properties required for compliance with a class or type under a given class are given in Table I.

Test Specimens

3. Testing for compliance with this classification shall be carried out on 9 by 4½ by 2½ or 3-in. rectangular brick as made, or on specimens of either size cut from larger units having dimensions not more than 3 in. in thickness, 6¾ in. in width, and 13½ in. in length.

Retests

4. Because of variables resulting from sampling and the lack of perfect reproducibility in tests conducted by different laboratories, resampling and retesting may be carried out when requested by either the purchaser or the manufacturer. This may apply in instances where the first test result does not conform to the limits prescribed in this classification. The final result to be used for each test shall be the average of the original and the retest figure.

Methods of Test

5. The properties enumerated in this classification shall be determined in accordance with the following methods of test of the American Society for Testing Materials:

(*a*) *Pyrometric Cone Equivalent.*—Method of Test for Pyrometric Cone Equivalent (P.C.E.) of Refractory Materials (ASTM Designation: C 24).[2]

(*b*) *Reheat Test for Super Duty Brick* (2910 F, 1600 C).—Schedule C of the Method of Test for Reheat Change of Refractory Brick (ASTM Designation: C 113).[2]

(*c*) *Panel Spalling Loss for Super Duty Brick* (3000 F, 1650 C).—Method of Panel Spalling Test for Super Duty Fireclay Brick (ASTM Designation: C 122).[2]

(*d*) *Load Test* (2460 F, 1350 C).—Schedule No. 2 of the Method of Testing Refractory Brick Under Load at High Temperatures (ASTM Designation: C 16).[2]

(*e*) *Alumina Content.*—Methods of Chemical Analysis of Refractory Materials (ASTM Designation: C 18).[2]

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[1] This proposal is being distributed as information only, by permission of Committee C-8 of the ASTM, and is the result of that committee's deliberations during its meeting held in Cincinnati, Ohio, February 2, 1955.

[2] 1952 Book of ASTM Standards, Part 3.

TABLE I.—FIRECLAY REFRACTORY BRICK CLASSIFIED ACCORDING TO CLASSES AND SUBDIVIDED INTO TYPES.

Class	Type	P.C.E., min	Panel Spalling Loss, max, per cent	Hot Load Subsidence, max, per cent	Reheat Shrinkage, max, per cent	Modulus of Rupture, min, psi	Other Test Requirements
Super duty	Regular	33	8 at 3000 F	...	1.0 at 2910 F	600	...
	Spall resistant	33	4 at 3000 F	...	1.0 at 2910 F	600	...
	Slag resistant	33	...	...	...	1000	Min bulk density, 140 lb per cu ft
High duty	Regular	31½	...	...	...	...	...
	Spall resistant	31½	10 at 2910 F	...	...	500	...
	Slag resistant	31½	...	...	...	1200	Min bulk density, 137 lb per cu ft, or max porosity, 15 per cent
Semi-silica		...	...	1.5 at 2460 F	...	300	Minimum silica content, 72 per cent
Medium duty		29	...	...	...	500	...
Low duty		19	...	...	...	600	...
Alumina-diaspore	50 per cent alumina	34	...	...	...	...	Alumina content, 50 ± 2.5 per cent
	60 per cent alumina	35	...	...	...	...	Alumina content, 60 ± 2.5 per cent
	70 per cent alumina	36	...	...	...	...	Alumina content, 70 ± 2.5 per cent

REPORT OF COMMITTEE C-9
ON
CONCRETE AND CONCRETE AGGREGATES*

Committee C-9 on Concrete and Concrete Aggregates held three meetings during the year: on June 18, 1954, during the Annual Meeting of the Society in Chicago, Ill.; on October 5, 1954, at Jackson, Miss.; and on February 3, 1955, in Cincinnati, Ohio, during Committee Week of the Society.

During the year the committee adopted memorials to the four members who had been lost through death: John J. Paine, who had been a member since 1942, died on March 20, 1954; Shreve Clark, who had been a member since 1940, died on May 26, 1954; R. B. Young, who had been a member since 1919, died on August 24, 1954; Earl R. Bryant, who had been a member since 1953, died on January 26, 1955.

The Sanford E. Thompson Award, established by the committee in 1938 in honor of its first chairman, is made for a paper of outstanding merit on concrete and concrete aggregates presented before the Society. The award this year will be made to R. C. Mielenz, U. S. Bureau of Reclamation, for his paper entitled "Petrographic Examination of Concrete Aggregates," which was presented at the 1954 Annual Meeting.[1]

RECOMMENDATIONS ACCEPTED BY THE ADMINISTRATIVE COMMITTEE ON STANDARDS

Subsequent to the 1954 Annual Meeting, Committee C-9 presented to the Society, through the Administrative Committee on Standards, the following five recommendations:

Tentative Specifications for:

Lightweight Aggregates for Insulating Concrete (**C 332 - 54 T**), and

Fly Ash for Use as an Admixture for Portland Cement Concrete (**C 350 - 54 T**).

Revision of Standard and Reversion to Tentative:

Specifications for Ready-Mixed Concrete (**C 94 - 48**).

Revision of Tentatives:

Tentative Specifications for Concrete Aggregates (**C 33 - 52 T**), and

Tentative Methods of Sampling and Testing Fly Ash for Use as an Admixture for Portland-Cement Concrete (**C 311 - 53 T**).

The first of these recommendations was accepted by the Standards Committee on November 5, 1954; the other four were accepted on September 28, 1954. The tentatives appear in the 1954 Supplement to the Book of ASTM Standards, Part 3.

NEW TENTATIVE

The committee recommends that the Method of Test for Ball Penetration in Fresh Cement Concrete be accepted for publication as tentative, as appended hereto.[2]

REVISION OF TENTATIVES

The committee recommends for revision and continuation as tentative the following:

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* Presented at the Fifty-eighth Annual Meeting of the Society, June 26-July 1, 1955.

[1] *Proceedings*, Am. Soc. Testing Mats., Vol. 54, p. 1188 (1954).

[2] The new tentative appears in the 1955 Book of ASTM Standards, Part 3.

Tentative Method of Test for Air Content (Volumetric) of Freshly Mixed Concrete (C 173 - 42 T):[3]

Replace this method with the Tentative Method of Test for Air Content of Freshly Mixed Concrete by the Volumetric Method appended hereto.[4] This revised method is based on extensive study and is believed far more practical than the present method.

Tentative Method of Test for Water Retention Efficiency of Liquid Membrane-Forming Compounds and Impermeable Sheet Materials for Curing Concrete (C 156 - 53 T):[5]

Section 10.—In item (14), change "inches" to "centimeters."

Section 11.—In line 5, change "inch" to "centimeter."

These revisions are for the purpose of bringing the test method (C 156) into agreement with one of the applicable specifications (C 309).

Tentative Method of Test for Soundness of Aggregates by Use of Sodium Sulfate or Magnesium Sulfate (C 88 - 46 T):[3]

Section 2(e).—Change to read as follows:

> (*e*) *Drying Oven.*—The oven shall be capable of being heated continuously between 105 and 110 C (221 and 230 F) and the rate of evaporation shall average at least 25 g per hour. This rate shall be determined by the loss of water from 1-liter, Griffin, low form beakers, each containing 500 g of water, placed at each corner and the center of each shelf of the oven, and heated for at least 4 hr during which period the doors of the oven shall be kept closed.

Section 3(a).—Change the last sentence to read as follows:

> The solution shall be cooled to a temperature of 21 ± 1 C (70 ± 2 F) and maintained at that temperature for at least 48 hr before use. Prior to each use, the salt cake, if any, in the container shall be broken up, the solution stirred thoroughly and the specific gravity of the solution determined. When used, the solution shall have a specific gravity not less than 1.151 nor more than 1.174. Discolored solution shall be discarded, or filtered and checked for specific gravity.

Section 3(b).—Change the last sentence as recommended for Section 3(*a*) except use 1.295 and 1.308 as the values for specific gravity.

These revisions are designed to clarify and improve items of procedure in the light of recent studies.

Tentative Method of Test for Potential Volume Change of Cement-Aggregate Combinations (C 342 - 54 T):[6]

Section 5(d).—Change to read as follows:

> (*d*) *Mixing of Mortar.*—Mixing shall be done in a bowl by vigorous and continuous squeezing and kneading with one hand, which shall be protected by a snug-fitting rubber glove. The materials for a batch shall be introduced into the bowl in the following sequence:
>
> (*1*) Place the water in the dry bowl,
>
> (*2*) Add the cement to the water and mix for 30 sec,
>
> (*3*) Add approximately one-half of the aggregate and mix for 30 sec, and
>
> (*4*) Add the remainder of the aggregate and mix for $1\frac{1}{2}$ min.

Section 2(a).—Change to read as follows:

> 2. (*a*) The mixing bowl used in the preparation of the mortar shall conform to the requirements specified in the Method of Test for Potential Alkali Reactivity of Cement-Aggregate Combinations (ASTM Designation C 227).

These revisions are necessary to correct an error made when this method was adopted and mechanical mixing prescribed. Available methods of mechanical mixing cannot satisfactorily be employed with the mortars contemplated by this method.

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[3] 1952 Book of ASTM Standards, Part 3.

[4] The revised tentative appears in the 1955 Book of ASTM Standards, Part 3.

[5] 1953 Supplement to Book of ASTM Standards, Part 3.

[6] 1954 Supplement to Book of ASTM Standards, Part 3.

Tentative Method of Test for Fundamental Transverse and Torsional Frequencies of Concrete Specimens (C 215 – 52 T):[3]

Replace this method with Tentative Method of Test for Fundamental Transverse, Longitudinal, and Torsional Frequencies of Concrete Specimens as appended hereto.[4]

The revised method includes procedures for determining fundamental longitudinal frequency and improvements in descriptions of apparatus and procedures generally.

Tentative Specifications for Concrete Aggregates (C 33 – 54 T):[6]

Section 4(c).—Change to read as follows:

(*c*) Fine aggregate for use in concrete which will be subject to frequent wetting, extended exposure to humid atmosphere, or contact with moist ground shall not contain any materials which are deleteriously reactive with the alkalies in the cement in an amount sufficient to cause excessive expansion of mortar or concrete except that if such materials are present in injurious amounts, the fine aggregate may be used with a cement containing less than 0.6 per cent alkalies calculated as sodium oxide or with the addition of a material that has been shown to inhibit undue expansion due to the alkali-aggregate reaction.

Note.—A number of methods for detecting potential reactivity have been proposed. However, they do not provide quantitative information on the degree of reactivity to be expected or tolerated in service. Therefore, evaluation of potential reactivity of an aggregate must be based upon judgment and in the interpretation of test data and examination of concrete structures containing the aggregates and cements for use in the new work. Results of the following tests will assist in making the evaluation:

(1) *Recommended Practice for Petrographic Examination of Aggregates for Concrete* (*ASTM Designation: C 295*).—Certain materials are known to be reactive with the alkalies in cements. These include the following forms of silica: opal, chalcedony, tridymite and cristobalite; intermediate to acid (silica-rich) volcanic glass such as is likely to occur in rhyolite, andesite, or dacite; certain zeolites such as heulandite; and certain constituents of some phyllites. Determination of the presence and quantities of these materials by petrographic examination is helpful in evaluating potential alkali reactivity. Some of these materials render an aggregate deleteriously reactive when present in quantities as little as 1.0 per cent or even less.

(2) *Tentative Method of Test for Potential Reactivity of Aggregates* (*Chemical Method*) (*ASTM Designation: C 289*).—In this test, where R_c signifies reduction in alkalinity and S_c dissolved silica, both in millimoles per liter, the following criteria may be used to evaluate potential reactivity:

(a) If R_c exceeds 70, the aggregate is considered potentially reactive if S_c is greater than R_c.

(b) If R_c is less than 70, the aggregate is considered potentially reactive if S_c is greater than $35 + \frac{R_c}{2}$.

The test can be made quickly and, while not completely reliable in all cases, provides helpful information, especially where results of the more time-consuming tests are not available.

(3) *Tentative Method of Test for Potential Alkali Reactivity of Cement-Aggregate Combinations* (*ASTM Designation: C 227*).—The results of this test, when made with the cement of highest alkali content likely to be used with the aggregate, furnish information on the likelihood of harmful reactions occurring. Combinations of aggregate and cement which have produced excessive expansions in this test usually should be considered potentially reactive. While the line of demarcation between non-reactive and reactive combinations is not clearly defined, expansion is generally considered to be excessive if it exceeds 0.05 per cent at 6 months or 0.10 per cent at one year. Expansions greater than 0.05 per cent at 6 months should not be considered excessive where the one year expansion remains below 0.10 per cent. Data for the 6-month tests should be considered only when one year results are not available.

Section 8(b).—Change to read as follows:

(*b*) Coarse aggregate for use in concrete which will be subject to frequent wetting, extended exposure to humid atmosphere. or contact with moist ground shall not contain any materials which are deleteriously reactive in an amount sufficient to cause excessive expansion of mortar or concrete with alkalies in cement, except that if such materials are present in injurious amounts, the coarse aggregate may be used with a cement containing less than 0.6 per cent alkalies calculated as sodium oxide or with the addition of a material that has been shown to inhibit undue expansion due to the alkali-aggregate reaction.

NOTE.—Methods for evaluating the reactivity of aggregates are discussed in the Note to Section 4(*c*).

These revisions are designed to take appropriate action with regard to specifications for aggregates, as a result of recent studies of cement-aggregate reaction.

Tentative Specifications for Ready Mixed Concrete (C 94 – 54 T):[6]

Section 9(a).—Change Paragraph (1) to read as follows:

(*1*) Mixed completely in a stationary mixer and the mixed concrete transported to the point of delivery in a truck agitator or in a truck mixer operating at agitating speed or in nonagitating equipment approved by the purchaser and meeting the requirements of Section 10(*a*). (Known as *central-mixed* concrete.)

Section 10.—Change the introductory paragraph to read as follows:

10. Central-mixed concrete which is designed for the purpose may be transported in suitable nonagitating equipment approved by the purchaser. The proportions of the concrete shall be approved by the purchaser and the following limitations shall apply:

Delete the present note.

Section 10(a).—Change the last sentence to read as follows:

Covers shall be provided for protection against the weather when required.

Section 10(c).—Add the following sentence at the end of this section:

If the slumps differ by more than 2 in., the nonagitating equipment shall not be used unless the conditions are corrected as provided in Paragraph (*d*).

New Section.—Add a new Section 10(*d*) to read as follows:

(*d*) If the requirements of Paragraph (*c*) are not met when the nonagitating equipment is operated at maximum capacity, for the maximum time of haul, and with the concrete mixed the minimum time, the equipment may still be used when operated using smaller loads, shorter hauls, or longer mixing times, or combinations thereof which will permit the requirements of Paragraph (*c*) to be met.

TENTATIVE REVISIONS OF STANDARDS

The committee recommends the following tentative revisions of standards:

Definitions of Terms Relating to Concrete and Concrete Aggregates (C 125 – 48):[3]

Add the following four definitions, the definition of "Sand" to supplement that appearing in ASTM Definitions C 58, and the definition of gravel to replace that now in Definitions C 125:

Sand.—(1) Granular material passing the $\frac{3}{8}$-in. sieve and almost entirely passing the No. 4 (4760-micron) sieve and predominantly retained on the No. 200 (74-micron) sieve, and resulting from natural disintegration and abrasion of rock or processing of completely friable sandstone; or (2) that portion of an aggregate passing the No. 4 (4760-micron) sieve and predominantly retained on the No. 200 (74-micron) sieve, and resulting from natural distintegration and abrasion of rock or processing of completely friable sandstone.

NOTE 1.—The definitions are alternatives to be applied under differing circumstances. Definition (1) is applied to an entire aggregate either in a natural condition or after processing. Definition (2) is applied to a portion of an aggregate.

NOTE 2.—Requirements for properties and grading should be stated in specifications. Fine aggregate produced by crushing rock, gravel, or slag commonly is known as "manufactured sand."

Gravel.—(1) Granular material predominantly retained on the No. 4 (4760-micron) sieve and resulting from natural disintegration and abrasion of rock or processing of weakly bound conglomerate; or (2) that portion of an aggregate retained on the No. 4 (4760-micron) sieve and resulting from disintegration and abrasion of rock or processing of weakly bound conglomerate.

Note 1.—The definitions are alternatives to be applied under differing circumstances. Definition (1) is applied to an entire aggregate either in a natural condition or after processing. Definition (2) is applied to a portion of an aggregate.

Note 2.—Requirements for properties and grading should be stated in specifications.

Fine Aggregate.—(1) Aggregate passing the $\frac{3}{8}$-in. sieve and almost entirely passing the No. 4 (4760-micron) sieve and predominantly retained on the No. 200 (74-micron) sieve; or (2) that portion of an aggregate passing the No. 4 (4760-micron) sieve and retained on the No. 200 (74-micron) sieve.

Note 1.—The definitions are alternatives to be applied under differing circumstances. Definition (1) is applied to an entire aggregate either in a natural condition or after processing. Definition (2) is applied to a portion of an aggregate.

Note 2.—The aggregate shall conform to the Tentative Definition of the Term Aggregate (ASTM Designation: C 58 - 28 T). Requirements for properties and grading should be stated in specifications. Fine aggregate produced by crushing rock, stone, or slag commonly is known as "manufactured sand."

Coarse Aggregate.—(1) Aggregate predominantly retained on the No. 4 (4760-micron) sieve; or (2) that portion of an aggregate retained on the No. 4 (4760-micron) sieve.

Note 1.—The definitions are alternatives to be applied under differing circumstances. Definition (1) is applied to an entire aggregate either in a natural condition or after processing. Definition (2) is applied to a portion of an aggregate.

Note 2.—The aggregate shall conform to the Tentative Definition of the Term Aggregate (ASTM Designation: C 58 - 28 T). Requirements for properties and grading should be stated in specifications.

These additional definitions are regarded as desirable additions to Definitions C 125 to provide authoritative basic definitions for reference.

Standard Specifications for Waterproof Paper for Curing Concrete (C 171 - 53):[3]

Section 3.—At the end of the first sentence, change "shall not show a moisture loss greater than 10 per cent of the original mixing water used" to read "shall not show a loss of water present in the test specimen at the time of application of the paper of more than 0.055 g per sq cm of surface."

Since materials tested for compliance are for the same purpose as those covered by Specification C 309 and are tested by the same Method C 156, this revision is regarded as desirable in order to require of them the same performance as is required by Specification C 309.

REVISION OF STANDARD AND REVERSION TO TENTATIVE

The committee recommends the revision and reversion to tentative of the following standards:

Standard Methods of Test for Unit Weight of Aggregate (C 29 - 42):[3]

Section 2(c).—In the last sentence, after "$\frac{1}{10}$" add "$\frac{1}{3}$." Revise the table of dimensional requirements to read as follows by the addition of requirements for the capacity of $\frac{1}{3}$ cu ft:

Capacity, cu ft	Inside Diameter, in.	Inside Height in.	Thickness of Metal, U. S. Gage	Size of Largest Particles of Aggregate, in.
$\frac{1}{10}$	6.00	6.10	No. 10 to No. 12	$\frac{1}{2}$
$\frac{1}{3}$	8.00	11.46	No. 10 to No. 12	1
$\frac{1}{2}$	10.00	11.00	No. 10 to No. 12	$1\frac{1}{2}$
1	14.00	11.23	No. 10 to No. 12	4

This revision provides for the use of a measure of a size not previously described for which a need has been encountered.

Standard Method of Test for Clay Lumps in Aggregates (C 142 - 39):[3]

Title.—Change to read as follows: "Method of Test for Clay Lumps in Natural Aggregates."

Section 1.—In line 4, add the word "Natural" before the word "Aggregates." Add the following sentence to

Section 1: "This method of test covers the procedure for the approximate determination of clay lumps in natural aggregate. It does not apply to such processed aggregates as expanded shales and clays."

This revision is designed to restrict the use of the method to samples of the type for which it is appropriate.

REVISION OF STANDARDS, IMMEDIATE ADOPTION

The committee recommends for immediate adoption revisions of the following standards and accordingly asks for the necessary nine-tenths affirmative vote at the Annual Meeting in order that these revisions may be referred to letter ballot of the Society:

Standard Method of Testing Air-Entraining Admixtures for Concrete (C 233 - 54):[3]

Section 6(a).—Add the following:

> The test results reported shall be the average of the individual test values obtained, except that, if one specimen of the test is manifestly faulty it shall be discarded and the remaining two values averaged. Should more than one specimen representing a given test be manifestly faulty, the entire test shall be discarded and repeated.

This revision clarifies the manner of obtaining the test result.

Standard Method of Test for Abrasion of Coarse Aggregate by Use of the Los Angeles Machine (C 131 - 51):[3]

Section 3(a).—Delete all references to cast-iron spheres. (This revision is contingent on similar action by Committee D-4.)

Standard Method of Test for Abrasion of Graded Coarse Aggregate by Use of the Deval Machine (D 289 - 53):[5]

Section 3(a).—Make the same change as recommended for Method C 131.

These revisions are recommended since it has been found that cast-iron spheres are not available.

Standard Method of Making and Curing Concrete Compression and Flexure Test Specimens in the Field (C 31 - 49):[3]

Section 6(c).—Replace the second and third sentences with the following:

> For specimens to be tested within 18 hours after capping, mixtures of sulfur and granular materials, which develop compressive strength equal to or greater than the anticipated strength of the specimen at time of test, may be used; this type of cap should be allowed to harden at least 2 hr before applying load.

Standard Method of Making and Curing Concrete Compression and Flexure Test Specimens in the Laboratory (C 192 - 54):[4]

Section 10(c).—Make the same change as recommended for Section 6(*c*) of Method C 31.

These revisions are designed to clarify the procedures for use of capping materials of the type referred to.

REAPPROVAL OF STANDARDS

The committee recommends that the following standards, which have stood without revision for six or more years, be reapproved as standard:

Standard Methods of Test for:

Voids in Aggregate for Concrete (**C 30 - 37**),
Organic Impurities in Sands for Concrete (**C 40 - 48**),
Surface Moisture in Fine Aggregate (**C 70 - 47**),
Flexural Strength of Concrete (Using Simple Beam with Third-Point Loading) (**C 78 - 49**),
Compressive Strength of Concrete Using Portions of Beams Broken in Flexure-Modified Cube Method (**C 116 - 49**),
Amount of Material Finer than No. 200 Sieve in Aggregates (**C 117 - 49**),
Flow of Portland-Cement Concrete by Use of the Flow Table (**C 124 - 39**),
Specific Gravity and Absorption of Coarse Aggregate (**C 127 - 42**),
Specific Gravity and Absorption of Fine Aggregate (**C 128 - 42**),
Sieve Analysis of Fine and Coarse Aggregates (**C 136 - 46**), and
Weight per Cubic Foot, Yield, and Air Content (Gravimetric) of Concrete (**C 138 - 44**).

Standard Methods of:

Securing, Preparing, and Testing Specimens from Hardened Concrete for Compressive and Flexural Strengths (**C 42 - 49**).

Standard Method of:

Measuring Length of Drilled Concrete Cores (**C 174 - 49**).

TENTATIVES CONTINUED WITHOUT REVISION

The committee recommends that the following tentatives, which have stood without revision for two or more years, be retained as tentative:

Tentative Methods of Test for:

Lightweight Pieces in Aggregate (C 123 - 53 T), and
Bleeding of Concrete (C 232 - 53 T).

Tentative Specifications for:

Liquid Membrane-Forming Compounds for Curing Concrete (C 309 - 53 T),
Lightweight Aggregates for Structural Concrete (C 330 - 53 T), and
Lightweight Aggregates for Concrete Masonry Units (C 331 - 53 T).

The subcommittees in charge of these tentatives recommend their continuation because of additional work that is in progress that may lead to early revisions.

EDITORIAL CHANGES

The committee recommends editorial changes in the following tentatives and standards:

Tentative Method of Test for Resistance of Concrete Specimens to Rapid Freezing and Thawing in Water (C 290 - 52 T):[3]

Section 2(a).—Change paragraph (*3*) to read as follows:

(*3*) The temperature of the heat-exchanging medium shall be uniform within 6 F throughout the specimen cabinet when measured at any given time, except during the transition between freezing and thawing and *vice versa*, at any point on the surface of any specimen container.

Section 3.—Add the word "(Note)" to the end of the first sentence and delete the second sentence. In line 18, change "±10 min" to "20 min"; in line 20, change "±5 min" to "10 min."

Tentative Method of Test for Resistance of Concrete Specimens to Rapid Freezing in Air and Thawing in Water (C 291 - 52 T):[3]

Section 2(a).—Make the same change as recommended for Method C 290 except omit the last word "container."

Section 3.—In Paragraph (*a*), last sentence, change "±10 min" to "20 min." In Paragraph (*b*), third sentence, change "±5 min" to "10 min."

Tentative Method of Test for Resistance of Concrete Specimens to Slow Freezing and Thawing in Water or Brine (C 292 - 52 T):[3]

Section 1.—In the first sentence, delete "or ice."

Section 2(a).—Make the same change as recommended for Method C 290. In addition, in Paragraph (*2*), line 6, delete "or ice."

Section 3.—Make the same changes as recommended for Method C 290.

Tentative Method of Test for Resistance of Concrete Specimens to Slow Freezing in Air and Thawing in Water (C 310 - 53 T):[5]

Section 2(a).—Make the same change as recommended for Method C 290 except omit the last word "container"

Section 3.—Make the same change as recommended for Method C 291.

Standard Method of Test for Air Content of Freshly Mixed Concrete by the Pressure Method (C 231 - 54).[3]

Section 2(d).—Revise first line to read:

(*d*) *Coil Spring.*—A coil spring or other means.

Section 2(e).—Revise first line to read:

(*e*) *Tube.*—A tube of appropriate diameter.

Section 2(f).—Revise first line to read:

(*f*) *Trowel.*—A trowel of the standard brick.

Section 2(g).—Revise to read:

(*g*) *Tamping Rod.*—A round, straight, steel rod, $\frac{5}{8}$ in. in diameter and approximately 24 in. in length, having one end rounded to a hemispherical tip, the diameter of which is $\frac{5}{8}$ in.

Section 2(h).—Revise first line to read:

(*h*) *Mallet.*—A mallet with a rubber or raw.

Section 2(i).—Revise first line to read:

(*i*) *Strike-off Bar.*—A strike-off bar consisting of a.

Section 2(j).—Revise first line to read:

(*j*) *Funnel.*—A funnel with spout fitting into.

Section 2(k).—Revise first line to read:

(*k*) *Measure.*—A measure having a ½- or 1-gal.

These revisions are intended to achieve adherence to standardized editorial treatment.

Standard Method of Making and Curing Concrete Compression and Flexure Test Specimens in the Field (C 31 - 49):[3]

Section 4.—Change the heading for this section from "Molds" to "Apparatus."

The recommendations in this report have been submitted to letter ballot of the committee, the results of which will be reported at the Annual Meeting.[7]

SUBCOMMITTEE ACTIVITIES

The work of Committee C-9 is carried out by three groups of subcommittees: Group 1, Administration, Fred Hubbard, chairman; Group II, Research, A. T. Goldbeck, chairman; and Group III, Specifications and Test Methods, Stanton Walker, chairman. All the subcommittees have been active during the year, and many of those that have not been responsible for recommendations included in this report may be expected to have recommendations in the near future.

A special subcommittee, of which L. E. Gregg is chairman, has been arranging for the preparation and publication of a new report to replace the "Report on Significance of Tests of Concrete and Concrete Aggregates," the first edition of which was issued in 1935 and the second in 1943. The new report will be entitled "Significance of Tests and Properties of Concrete and Concrete Aggregates" and will consist of a résumé of present information on the significance of the properties of concrete and concrete aggregates and the tests by which they are studied and determined. The publication will include four parts and 39 separate contributions prepared by 44 authors.[8]

This report has been submitted to letter ballot of the committee, which consists of 129 active members, commanding 98 votes, plus 6 honorary members having voting privileges; 121 members returned their ballots, of whom 116 have voted affirmatively and 1 negatively.

Respectfully submitted on behalf of the committee,

W. H. PRICE,
Chairman.

BRYANT MATHER,
Secretary.

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[7] The letter ballot vote on these recommendations was favorable; the results of the vote are on record at ASTM Headquarters.

[8] Issued as separate publication *ASTM STP No. 169.*

REPORT OF COMMITTEE C-11
ON
GYPSUM*

Committee C-11 on Gypsum held two meetings during the year: in Chicago, Ill., on June 15 and 16, 1954, and in Cincinnati, Ohio, on February 1 and 2, 1955. The subcommittees met the day prior to the meetings of the main committee.

The committee now consists of 33 members, of whom 12 are classified as producers, 10 as consumers, and 11 as general interest members. This represents an increase of 13 members since the Annual Report in 1954.

During the year the committee suffered the loss of a former chairman and prominent member in the untimely death of Lansing Sadler Wells. A resolution has been placed on record and a copy sent to Mrs. Wells.

RECOMMENDATIONS ACCEPTED BY THE ADMINISTRATIVE COMMITTEE ON STANDARDS

Subsequent to the 1954 Annual Meeting, Committee C-11 joined with Committee C-7 in presenting to the Society through the Administrative Committee on Standards the recommendation for revisions of the Tentative Specification for Inorganic Aggregates for Use in Interior Plasters (**C 35 - 53 T**). This recommendation was accepted by the Standards Committee on December 22, 1954, and the revised specification appears in the 1954 Supplement to Book of ASTM Standards, Part 3.

ADOPTION OF TENTATIVES AS STANDARD WITHOUT REVISION

The committee recommends that the following tentatives be approved for reference to letter ballot of the Society for adoption as standard without change:

Tentative Specifications for:

Gypsum Concrete (**C 317 - 54 T**),[1] and
Gypsum Formboard (**C 318 - 53 T**).[2]

REVISIONS OF STANDARDS, IMMEDIATE ADOPTION

The committee recommends for immediate adoption revisions in the following standards and accordingly asks for the necessary nine-tenths affirmative vote at the Annual Meeting in order that the revisions may be referred to letter ballot of the Society:

Standard Definitions of Terms Relating to Gypsum (C 11 - 50):[3]

Add the following new definition in the form of a note following "Gypsum Wallboard":

NOTE: *Type X, Gypsum Wallboard.*—"Type X" (Special Fire Retardant) designates gypsum wallboard with a specially formulated core which provides greater fire resistance than regular gypsum wallboard of the same thickness.

Standard Specification for Gypsum Wallboard (C 36 - 54):[1]

Section 2.—Add the following sentence in italics:

"Type X" (Special Fire Retardant) designates gypsum wallboard with a specially formulated core which provides greater fire resistance than regular gypsum wallboard of the same thickness.

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* Presented at the Fifty-eighth Annual Meeting of the Society, June 26–July 1, 1955.

[1] 1954 Supplement to Book of ASTM Standards, Part 3.

[2] 1953 Supplement to Book of ASTM Standards, Part 3.

[3] 1952 Book of ASTM Standards, Part 3.

Standard Specifications for Gypsum Plaster (C 28 – 50):[3]

Change Section 12 to read as follows:

12. Gypsum wood-fiber plaster shall contain not less than 66.0 per cent by weight of $CaSO_4 \cdot \frac{1}{2}H_2O$ and not less than 0.75 per cent by weight of wood-fiber made from non-staining wood when tested in accordance with ASTM Designation C 26.

The recommendations in this report have been submitted to letter ballot of the committee, the results of which will be reported at the Annual Meeting.[4]

This report has been submitted to letter ballot of the committee, which consists of 33 members; 27 members returned their ballots, of whom 26 have voted affirmatively and 0 negatively.

Respectfully submitted on behalf of the committee,

G. W. JOSEPHSON,
Chairman.

O. H. STOREY,
Secretary.

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[4] The letter ballot vote on these recommendations was favorable; the results of the vote are on record at ASTM Headquarters.

REPORT OF COMMITTEE C-13

ON

CONCRETE PIPE*

Committee C-13 on Concrete Pipe held one meeting during the year: in Chicago, Ill., on September 9, 10, and 11, 1954.

The present membership of the committee consists of 42 members, of whom 21 are classified as producers, 16 as consumers, and 5 as general interest members.

The committee approved an initial set of regulations as supplemental to those published by the Society.

A revision in the scope of Committee C-13 was approved by the Board of Directors during the year covering the addition of the words "and drainage." The committee has already developed specifications for concrete pipe used for drainage purposes.

NEW TENTATIVES

The committee recommends that the following specifications be accepted for publication as tentatives, as appended hereto:[1]

Tentative Specifications for:

Reinforced-Concrete Low-Head Pressure Pipe, and
Reinforced-Concrete Low-Head Internal Pressure Sewer Pipe.

ADOPTION OF TENTATIVE REVISIONS AS STANDARD

The committee recommends that tentative revisions of the following standards be approved for reference to letter ballot of the Society for adoption as standard:

Standard Specifications for Concrete Sewer Pipe (C 14 - 54):[2]

Tentative revision of Sections 2, 6, 14(*b*), 15, 17(*c*), 24, Table I, Fig. 1, and Fig. 2.

Standard Specifications for Reinforced-Concrete Sewer Pipe (C 75 - 54):[2]

Tentative revision of Sections 7, 13, New Section 14, 23, 25, 27(*c*), 30, 31, 32(*d*), Fig. 2, and Fig. 3.

Standard Specifications for Reinforced-Concrete Culvert Pipe (C 76 - 54):[2]

Tentative revision to Sections 7, 13, New Section 14, 25, 27, 29(*c*), 32, 33, 34(*d*), Fig. 2, and Fig. 3.

Standard Specifications for Concrete Irrigation Pipe (C 118 - 52):[3]

Tentative revisions[2] to Title, Sections 1, 2, 6, 12, 13(*a*), 15(*c*), and Fig. 1.

REVISION OF STANDARDS, IMMEDIATE ADOPTION

The committee recommends for immediate adoption revision of the following standards and accordingly asks for a nine-tenths affirmative vote at the Annual Meeting in order that these revisions may be referred to letter ballot of the Society:

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* Presented at the Fifty-eighth Annual Meeting of the Society, June 26–July 1, 1955.

[1] The new tentatives appear in the 1955 Book of ASTM Standards, Part 3.

[2] 1954 Supplement to Book of ASTM Standards, Part 3.

[3] 1952 Book of ASTM Standards, Part 3.

Standard Specifications for Concrete Sewer Pipe (C 14 – 54):[2]

Section 20.—Change to read as follows:

20. (*a*) *Acceptance or Rejection as to Strength Properties.*—Pipe shall be acceptable under the strength tests when all test specimens conform to the test requirements. Should any of the preliminary test specimens provided for in Section 10(*b*) fail to meet the test requirements, then the manufacturer will be allowed a retest on two additional specimens for each specimen that failed, and the pipe shall be acceptable only when all these retest specimens meet the strength requirements.

(*b*) *Acceptance or Rejection as to Other than Strength Properties.*—In other than strength tests when not more than 20 per cent of the specimens fail to pass the requirements of the specification, the manufacturer may cull his stock and may eliminate whatever quantity of pipe he desires and must so mark those pipe that they will not be shipped. The required tests shall be made on the balance of the order and they shall be accepted if they conform to the test requirements.

New Section.—Add a new Section 25 as follows, renumbering the subsequent sections accordingly:

25. *Joints.*—The ends of the pipe shall be so formed that when the pipe are laid together and joined, they will make a continuous and uniform line of pipe with a smooth and regular interior surface. The joints shall be of such design as will permit effective cementing to reduce leakage and infiltration to a satisfactory minimum and to permit placement without appreciable irregularities in the flow line.

Unless otherwise specified, nonreinforced concrete pipe under these specifications shall have bell and spigot, tongue and groove, or other approved type joint.

Table II.—Revise as shown in the accompanying Table I.

TABLE I.—DIMENSIONS OF CONCRETE SEWER PIPE.

(Revision of Table II, C 14.)

Internal Diameter, D, in.	Laying Length, L, ft.	Inside Diameter at Mouth of Socket, D_s, in.[a]	Depth of Socket, L_s, in.	Minimum Taper of Socket, $H:L_s$	Thickness of Barrel, T, in.[b]		Thickness of Socket, T_s
					Standard Strength Pipe	Extra Strength Pipe	
1	*2*	*3*	*4*	*5*	*6*	*7*	*8*
4	2, 2½, 3	6	1½	1:20	9/16	¾	The thickness of the socket ¼ in. from its outer end shall be not less than three fourths of the thickness of the barrel of the pipe.
6	2, 2½, 3	8¼	2	1:20	⅝	¾	
8	2, 2½, 3, 4	10¾	2¼	1:20	¾	⅞	
10	2, 2½, 3, 4	13	2½	1:20	⅞	1	
12	2, 2½, 3, 4	15¼	2½	1:20	1	1⅜	
15	2, 2½, 3, 4	18¾	2½	1:20	1¼	1⅝	
18	2, 2½, 3, 4	22¼	2¾	1:20	1½	2	
21	2, 2½, 3, 4	26	2¾	1:20	1¾	2¼	
24	2, 2½, 3, 4	29½	3	1:20	2⅛	2⅝	

[a] When pipes are furnished having an increase in thickness over that given in column 6, then the diameter of socket shall be increased by an amount equal to twice the increase of thickness of barrel.

[b] Where tongue and groove pipe is furnished, it shall have a minimum shell thickness of 1¾ inches.

Table III.—Delete the Note which appears at the top of Table III, and add the following requirements for "Length of Two Opposite Sides, in.," under the heading "Limits of Permissible Variation, in.":

Nominal Size, Internal Diameter, in.	Variation, in.
4	¼
6	¼
8	5/16
10	⅜
12	⅜
15	7/16
18	½
21	9/16
24	9/16

Standard Specifications for Reinforced Concrete Sewer Pipe (C 75 – 54):[2]

Section 13.—In the last sentence, change "48 in." to read "36 in."

Add the following sentence: "The continuity of the circumferential reinforcing steel shall not be destroyed during the manufacture of the pipe."

Section 20.—Change to read as follows:

20. A purchaser of pipe, whose needs require shipments at intervals over extended periods of time, shall be entitled to preliminary tests of not more than three sections of pipe covering each size in which he is interested. The acceptability of pipe having a diameter greater than 72 in. shall be determined by tests of the quality of the concrete as placed in the pipe and by examination of the quality, amount, and accuracy of placement of the reinforcement. The compressive strength of the concrete shall be determined by tests on cores drilled from the barrel of the pipe, or from 6 by 12-in. test cylinders made from concrete used in making the pipe and manufactured and cured under comparable conditions with the pipe. The absorption test may be determined by tests on cores drilled from the pipe. When mutually agreed upon by the purchaser and the seller, pipe having an internal diameter of 72 in. and less may also be accepted on the same basis as for pipe larger than 72 in. as described above, in which case the specified strength requirements for full size pipe shall be waived.

Cores drilled from the barrel of the pipe shall have a diameter not less than 3½ in. They shall be secured, prepared for testing, and tested by methods prescribed in the Methods of Securing, Preparing and Testing Specimens from Hardened Concrete for Compressive and Flexural Strength (ASTM Designation: C 42).

When the cores cut from a section of pipe successfully meet the strength test requirement, the core-holes shall be plugged and sealed by the manufacturer in such a manner that the pipe section will meet all of the test requirements of this specification. Pipe sections so sealed shall be considered as satisfactory for use.

Compression tests of cylinders shall be made in accordance with the Method of Test for Compressive Strength of Molded Concrete Cylinders (ASTM Designation: C 39) of the American Society for Testing Materials.

After these preliminary tests, a purchaser shall be entitled to additional tests in such numbers and at such times as he may deem necessary, provided that the total number of pipe tested shall not exceed 1 per cent of the pipe delivered.

Section 32.—In the first sentence change the word "stenciled" to read "marked."

Table I.—Remove the Note which appears at the top of Table I.

Add the following sentence to Footnote *a*:

[a] Where two lines of circular steel are specified, the inner cage shall contain not less than 50 per cent and the outer cage shall contain not less than 40 per cent of the total area of steel listed above for each size of pipe, but, in no case, shall the total area of steel in two cages be less than the total specified in the Table.

Standard Specifications for Reinforced Concrete Culvert Pipe (C 76 - 54):[2]

Section 13.—Change to read as recommended for Section 13 of Standard Specifications C 75 above.

Section 21.—Change to read as recommended for Section 20 of Standard Specifications C 75 above.

Section 34.—In the first sentence change the word "stenciled" to read "marked."

Table I and Table II.—Under the columns headed "Circular Reinforcement in Circular Pipe," change the word "each" to read "totaling," and double the numerical value of each number following the present word "each."

Add a Footnote *c* as follows:

[c] Where two lines of circular steel are specified, the inner cage shall contain not less than 50 per cent and outer cage shall contain not less than 40 per cent of the total area of steel listed above for each size of pipe, but in no case, shall the total area of steel used in two cages be less than the total specified in the table.

The reference to this footnote shall follow the word "lines" each place the word appears under the column headed "Circular Reinforcement in Circular Pipe."

Standard Specifications for Concrete Irrigation and Drainage Pipe (C 118 - 52):[3]

Section 11.—Change to read as follows:

11. (a) When used for irrigation systems, the ends of the pipe shall be so formed that when laid together and joined they will make a continuous

and uniform line of pipe with a smooth and regular interior surface. The joints shall be of such design as will permit effective cementing and placement without appreciable irregularities in the flow line.

(*b*) When used for drainage, joints shall be furnished which will preserve alignment in the trench when laid without mortar or other jointing material, allow the entrance of water, and minimize the entrance of solids.

Table I.—Change title to read: "Physical Test Requirements for Standard Concrete Irrigation and Drainage Pipe."

Add the following new pipe sizes and test requirements for these sizes of pipe:

Internal Diameter, in.	Minimum Shell Thickness, in.	Test Requirements		
		Internal Hydrostatic Pressure on Individual Sections, psi	Minimum Three-Edge-Bearing Load, lb per linear ft	Maximum Absorption, per cent
4......	¾	75	1000	8
*5......	¾	75	1000	8

* Special sizes obtainable in some localities.

The recommendations in this report have been submitted to letter ballot of the committee, the results of which will be reported at the Annual Meeting.[4]

ACTIVITIES OF SUBCOMMITTEES

Subcommittees and task groups were discharged with the thanks and appreciation of the committee, for work which has been done on long range planning, study of need for a specification for precast concrete manholes for access to nonpressure lines, and study of desirability of combining specifications C 75 and C 76 or to coordinate them and bring them up to date in accordance with present practices and wording.

The task group which studied the desirability of combining Specification C 75 and C 76 (M. G. Spangler, chairman) recommended that these specifications remain as separate standards, this action being accepted by the committee. The report of this task group also included a comprehensive revision of the Specification for Reinforced Concrete Culvert Pipe (C 76), which has been distributed to the committee for further consideration.

The task group appointed to study the need for a specification for precast concrete manholes for access to nonpressure lines (Peter Van Kuran, chairman), after conducting a thoroughgoing canvass of the industry, presented a recommendation to take no action at the present time due to the comparatively small volume of production of these items and the various types of design now in use. This recommendation was approved by the committee.

The Task Group on Specifications for Low-Head Concrete Pressure Pipe (H. G. Curtis, chairman) presented two specifications to the committee for publication as tentative. These recommendations appear elsewhere in this report. This task group was retained until a permanent subcommittee is appointed to advise on these specifications.

This report has been submitted to letter ballot of the committee, which consists of 42 members; 40 members returned their ballots, of whom 39 have voted affirmatively and 0 negatively.

Respectfully submitted on behalf of the committee,

R. R. LITEHISER,
Chairman.

HOWARD F. PECKWORTH,
Secretary.

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[4] The letter ballot vote on these recommendations was favorable; the results of the vote are on record at ASTM Headquarters.

REPORT OF COMMITTEE C-15
ON
MANUFACTURED MASONRY UNITS*

Committee C-15 on Manufactured Masonry Units held two meetings during the past year: on June 15, 1954, in Chicago, Ill., in conjunction with the Annual Meeting of the Society, and on February 2, 1955, in Cincinnati, Ohio, during ASTM Committee Week.

At the present time Committee C-15 consists of 71 members, of whom 34 are classified as producers, 17 as consumers, and 20 as general interest members.

During the past year, three valued and respected members of Committee C-15 were lost by death, namely, T. R. Lawson, J. J. Paine, and E. R. Bryant.

A new Subcommittee V has been formed to prepare standards for waterproofing materials for unit masonry walls. Since its formation, this subcommittee has met and has started an intensive study of the scope of its proposed activities.

The preparation of a specification for industrial floor brick has been assigned to Subcommittee IX on Chemical-Resistant Units.

RECOMMENDATIONS ACCEPTED BY THE ADMINISTRATIVE COMMITTEE ON STANDARDS

Subsequent to the 1954 Annual Meeting, Committee C-15 presented to the Society through the Administrative Committee on Standards revisions of Tentative Specification for Drain Tile (C 4 - 50 T). This recommendation was accepted by the Standards Committee on September 28, 1954, and the revised specification appears in the 1954 Supplement to the Book of ASTM Standards, Part 3.

TENTATIVE REVISIONS OF STANDARDS

The committee recommends for publication the following tentative revisions of standards:

Specifications for Structural Clay Load-Bearing Wall Tile (C 34 - 52):[1]

Specifications for Structural Clay Non-Load-Bearing Tile (C 56 - 52):[1]

Specifications for Structural Clay Floor Tile (C 57 - 52):[1]

Section 7.—Delete this section. Section 7 on Marking is being deleted on the basis that the presence or absence of a trade mark on the product in no way relieves the manufacturer of the responsibility of meeting the physical requirements of the specification.

ADOPTION OF TENTATIVE AS STANDARD WITHOUT REVISION

The committee recommends that the Tentative Specifications for Drain Tile (**C 4 - 54 T**)[2] be approved for reference to letter ballot of the Society for adoption as standard without revision.

ADOPTION OF TENTATIVE REVISIONS AS STANDARD

The committee recommends that the tentative revisions of the following standards be approved for reference to letter ballot of the Society for adoption as standard:

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* Presented at the Fifty-eighth Annual Meeting of the Society, June 26–July 1, 1955.

[1] 1952 Book of ASTM Standards, Part 3.

[2] 1954 Supplement to Book of ASTM Standards, Part 3.

Standard Specification for Structural Clay Load-Bearing Wall Tile (C 34 – 52):[1]

This tentative revision was issued September 9, 1953, and relates to the Table in Section 3(*a*).

Standard Specifications for Vitrified Clay Filter Block (C 159 – 51):[1]

This tentative revision was issued September 5, 1952, and relates to Section 9(*a*).

Definition of Terms Relating to Structural Clay Tile (C 43 – 50):[1]

This tentative revision was issued September 5, 1952, and relates to new definitions for "Nominal Dimensions," "Specified Dimensions," and "Average Dimension of Tile in a Shipment." It is recommended that the definition for "Specified Dimensions" be revised to read as follows:

> *Specified Dimensions.*—The dimensions to which masonry units or constructions are required to conform. Actual (Measured) dimensions may differ from the specified dimensions by permissible variations.

REVISION OF STANDARDS, IMMEDIATE ADOPTION

The committee recommends approval of the following revisions for immediate adoption and accordingly requests the necessary nine-tenths affirmative vote at the Annual Meeting in order that the revisions may be referred to letter ballot of the Society:

Standard Specifications for Concrete Building Brick (C 55 – 52):[1]

Section 5(b).—Change to read as follows: "The brick shall be sampled and tested in accordance with the ASTM Methods of Sampling and Testing Concrete Masonry Units (C 140)."

Standard Methods of Sampling and Testing Concrete Masonry Units (C 140 – 52):[1]

Section 1.—Delete the Note.

REAPPROVAL OF STANDARD

The committee recommends that the Standard Specifications for Paving Brick (**C 7 – 42**), which has stood without revision for more than six years, be reapproved as standard.

TENTATIVE CONTINUED WITHOUT REVISION

The committee recommends that the Tentative Specification for Ceramic Glazed Structural Clay Facing Tile, Facing Brick and Solid Masonry Units (**C 126 – 52 T**), which has stood without revision for two years, be retained as tentative.

The recommendations in this report have been submitted to letter ballot of the committee, the results of which will be reported at the Annual Meeting.[3]

This report has been submitted to letter ballot of the committee, which consists of 71 members; 57 members have returned their ballots, of whom 39 have voted affirmatively and 0 negatively.

Respectfully submitted on behalf of the committee,

J. W. WHITTEMORE,
Chairman.

M. H. ALLEN,
Secretary.

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[3] The letter ballot vote on these recommendations was favorable; the results of the vote are on record at ASTM Headquarters.

EDITORIAL NOTE

Subsequent to the Annual Meeting, Committee C-15 presented to the Society through the Administrative Committee on Standards the following recommendations:

Revision of Tentative Specifications for:

Ceramic Glazed Structural Clay Facing Tile, Facing Brick, and Solid Masonry Units (C 126 – 52 T),

Tentative Revision of Standard Specifications for:

Building Brick (Solid Masonry Units Made from Clay or Shale) (C 62 – 50),
Facing Brick (Solid Masonry Units Made from Clay or Shale) (C 216 – 50), and

Tentative Revision of Standard Methods of:

Sampling and Testing Brick (C 67 – 50).

These recommendations were accepted by the Standards Committee on September 15, 1955, and the revised tentative and tentative revisions of standards appear in the 1955 Book of ASTM Standards, Part 3.

REPORT OF COMMITTEE C-16
ON
THERMAL INSULATING MATERIALS*

Committee C-16 on Thermal Insulating Materials and its subcommittees held two meetings during the past year: at Shawnee-on-Delaware, Pa., on October 4, 5, and 6, 1954, and at Savannah, Ga., on March 2, 3, and 4, 1955.

The committee consists of 78 voting members, 24 nonvoting members, 3 honorary members, 3 associate members, and 1 consulting member. The voting membership is classified as 40 producers, 18 consumers, and 20 general interest members.

A new subcommittee was formed and designated S-XI on Reflective Insulation with G. E. Gronemeyer as chairman.

RECOMMENDATIONS ACCEPTED BY THE ADMINISTRATIVE COMMITTEE ON STANDARDS

Subsequent to the 1954 Annual Meeting, Committee C-16 presented to the Society through the Administrative Committee on Standards the following recommendations:

Tentative Specifications for:

Corkboard Thermal Insulation (**C 352 - 54 T**),

Tentative Method of Test for:

Mean Specific Heat of Thermal Insulation (**C 351 - 54 T**),
Adhesion of Dried Thermal Insulating Cements (**C 353 - 54 T**),
Compressive Strength of Thermal Insulating Cement (**C 354 - 54 T**),
Water Vapor Transmission of Materials Used in Building Construction (**C 355 - 54 T**), and
Linear Shrinkage of Preformed High Temperature Thermal Insulation (**C 356 - 55 T**).

Tentative Method C 351 was accepted by the Standards Committee on October 4, 1954, and appears in the 1954 Supplement to Book of ASTM Standards, Part 3. Tentative Method C 356 was accepted by the Standards Committee on March 7, 1955, and the remaining new tentatives were accepted on December 22, 1954; they are available as separate reprints.

NEW TENTATIVES

The committee recommends that the Tentative Specifications for Molded Cork Pipe Insulation for Low Temperatures be accepted for publication as tentative as appended hereto.[1]

REVISION OF TENTATIVES

The committee recommends revisions of the following tentative specifications:

Tentative Specifications for Mineral Wool Batt Insulation (Industrial Type) (C 262 – 51 T):[2]

Section 6(d).—In the first sentence, change the words "Btu in. per hr sq ft deg Fahr" to read "Btu in. per sq ft per hr per deg F."

Section 6(e).—Change to read as follows:

> (*e*) *Fire Resistance*.—When required, the degree of combustibility shall be determined by a test method acceptable to both the seller and the purchaser.

Section 8(c).—Delete.

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* Presented at the Fifty-eighth Annual Meeting of the Society, June 26–July 1, 1955.

[1] The new tentative appears in the 1955 Book of ASTM Standards, Part 3.

[2] 1952 Book of ASTM Standards, Part 3.

Tentative Specifications for Mineral Wool Felt Insulation (Industrial Type) (C 264 - 51 T):[2]

Revise as appended hereto.[3]

These revisions were made to bring the specifications up to date and in line with product development.

REVISIONS OF STANDARDS AND REVERSION TO TENTATIVE

The committee recommends that the following standards be revised as indicated and reverted to tentative status:

Standard Specification for Structural Insulating Board Made from Vegetable Fibers (C 208 - 48):[2] Revise as appended hereto.[3]

Standard Method of Test for Flexural Strength of Preformed Block-Type Thermal Insulation (C 203 - 51):[2] Revise as follows:

Title.—Change to read as follows:

> Standard Method of Test for Breaking Strength and Calculated Flexural Strength of Preformed Block-Type Thermal Insulation.

Section 1.—Change the section on Scope to read as follows:

> 1. This method of test covers the procedure for determining the flexural strength and breaking strength of preformed block-type thermal insulation.

Delete the Note at the end of this section.

Section 4(a).—Add to Paragraph (*a*) the following sentence: "The width and thickness of test specimens shall be recorded to the nearest 0.01 in."

Section 4(b).—Delete from the fourth sentence the following: "Where the original surfaces of the block are substantially plane and parallel."

Section 4(c).—Add the following Note:

> NOTE.—If the material is one that may be chemically affected by heating at 215 F to 250 F, the specimen shall be dried in a desiccator at 120 F to 140 F.

Section 7.—Revise Paragraph (*a*) to read as follows:

> 7. (*a*) When specified, the average value of the flexural strength (*R*) in pounds per square inch shall be reported.

Add the following new Paragraph (*b*):

> (*b*) When specified, the average value of breaking load (*W*) in pounds, at which the specimen failed under maximum stress, shall be reported for each nominal width and thickness tested.

Standard Methods of Testing Structural Insulating Board Made from Vegetable Fibers (C 209 - 48):[2] Revise as appended hereto.[3]

Standards C 208 - 48 and C 209 - 48 were revised to bring them up-to-date with respect to new products and methods of test. Two new classes of structural insulating board and new test procedures and conditions for testing have been added. Reference is made to ASTM methods of test where an appropriate method is available.

In existing Methods C 203 - 51, flexural strength in pounds per square inch is derived from the breaking load (load at which the test specimen fails), whereas in the revised form reporting the flexural strength or breaking load is made optional.

ADOPTION OF TENTATIVES AS STANDARD WITHOUT REVISION

The committee recommends that the following tentative specifications be approved for reference to letter ballot of the Society for adoption as standard without revision:

Tentative Specifications for:

85 per cent Magnesia Block-Type Thermal Insulation (**C 319 - 53 T**),[4]

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[3] The revised tentative appears in the 1955 Book of ASTM Standards, Part 3.

[4] 1953 Supplement to Book of ASTM Standards, Part 3.

85 per cent Magnesia Molded-Type Thermal Insulation for Pipes (**C 320 - 53 T**),[4] and

Recommended Practice for:

Clearance of Preformed Thermal Pipe Insulation (**C 312 - 53 T**).[4]

REAPPROVAL OF STANDARDS

The committee recommends that the following standards, which have stood for six or more years without revision, be reapproved as standard:

Standard Specification for:

85 per cent Magnesia Thermal Insulating Cement (**C 193 - 48**),
Asbestos Thermal Insulating Cement (**C 194 - 48**),
Expanded or Exfoliated Vermiculite Thermal Insulating Cement (**C 196 - 48**),
Diatomaceous Silica Thermal Insulating Cement (**C 197 - 48**),

Standard Method of:

Sampling and Mixing Thermal Insulating Cement (**C 163 - 44**), and
Test for Thermal Conductivity of Materials by Means of the Guarded Hot Plate (**C 177 - 45**).

TENTATIVES CONTINUED WITHOUT REVISION

The committee recommends that the following tentatives which have stood without revision for two or more years be retained as tentative:

Tentative Specifications for:

Mineral Wool Molded-Type Pipe Insulation (for Elevated Temperatures) (**C 281 - 52 T**),
Cellular Asbestos Paper Thermal Insulation for Pipes (**C 298 - 52 T**),
Laminated Asbestos Thermal Insulation for Pipes (**C 299 - 52 T**),
Mineral Wool Pipe Insulation; Molded-Type (Low Temperatures) (**C 300 - 52 T**),

Tentative Methods of Test for:

Density of Preformed Pipe Covering Type Thermal Insulation (**C 302 - 52 T**),
Density of Preformed Block Type Thermal Insulation (**C 303 - 52 T**), and
Vibration Resistance of Preformed Thermal Insulation for Pipes (**C 304 - 52 T**).

These tentatives are undergoing review in the subcommittees with a view to advancing them to standard.

The recommendations in this report have been submitted to letter ballot of the committee, the results of which will be reported at the Annual Meeting.[5]

This report has been submitted to letter ballot of the committee, which consists of 78 voting members; 56 members returned their ballots, all of whom have voted affirmatively.

Respectfully submitted on behalf of the committee,

E. R. QUEER,
Chairman.

W. L. GANTZ,
Secretary.

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[5] The letter ballot vote on these recommendations was favorable; the results of the vote are on record at ASTM Headquarters.

REPORT OF COMMITTEE C-17

ON

ASBESTOS-CEMENT PRODUCTS*

Committee C-17 on Asbestos-Cement Products and its subcommittees met in Cincinnati, Ohio, on February 3, 1955, during Committee Week of the Society.

The membership of the committee consists of 33 members, 28 of whom are voting members; 10 are classified as producers, 3 as consumers, and 15 as general interest members.

ADOPTION OF TENTATIVES AS STANDARDS WITHOUT REVISION

The committee recommends that the following five tentatives be approved for reference to letter ballot of the Society for adoption as standard without revision:

Tentative Specifications and Methods of Test for Flat Asbestos-Cement Sheets (**C 220 - 53 T**),[1]
Tentative Specifications and Methods of Test for Corrugated Asbestos-Cement Sheets (**C 221 - 53 T**),[1]
Tentative Specifications and Methods of Test for Asbestos-Cement Roofing Shingles (**C 222 - 53 T**),[1]
Tentative Specifications and Methods of Test for Asbestos-Cement Siding Shingles and Clapboards (**C 223 - 53 T**),[1] and
Tentative Specifications for Asbestos-Cement Pressure Pipe (**C 296 - 53 T**).[1]

The recommendations in this report have been submitted to letter ballot of the committee, the results of which will be reported at the Annual Meeting.[2]

ACTIVITIES OF SUBCOMMITTEES

The committee voted to develop methods of test and standards for asbestos-cement sewer pipe, and the subcommittees will undertake this project.

Subcommittee I on Methods of Test (S. E. Williams, chairman) is continuing its studies to develop a test for handleability of asbestos-cement products. Another task group is engaging in work on a method to determine the amounts of organic material in asbestos-cement products. A third group is studying the characteristics of completeness of cure and the development of a test to indicate degree of cure.

This report has been submitted to letter ballot of the committee, which consists of 28 voting members; 18 members returned their ballots, of whom 16 have voted affirmatively and 0 negatively.

Respectfully submitted on behalf of the committee,

DAVID WOLOCHOW,
Chairman.

CHESTER C. KELSEY,
Secretary.

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* Presented at the Fifty-eighth Annual Meeting of the Society, June 26–July 1, 1955.

[1] 1953 Supplement to Book of ASTM Standards, Part 3.

[2] The letter ballot vote on these recommendations was favorable; the results of the vote are on record at ASTM Headquarters.

REPORT OF COMMITTEE C-19

ON

STRUCTURAL SANDWICH CONSTRUCTIONS*

Committee C-19 on Structural Sandwich Constructions held two meetings during the year: at the Purdue Memorial Union, Lafayette, Ind., on October 19 and 20, 1954, and at U. S. Forest Products Laboratory, Madison, Wis., on April 27 and 28, 1955.

The present committee consists of 56 members, with 48 voting members, of whom 21 are classified as producers, 7 as consumers, and 20 as general interest members.

NEW TENTATIVES

Committee C-19 recommends that the following test methods be accepted for publication as tentative, as appended hereto:[1]

- Method of Flatwise Compressive Strength of Sandwich Cores,
- Method of Edgewise Compressive Strength of Flat Sandwich Construction,
- Method of Test for Delamination Strength of Honeycomb Type Core Material, and
- Methods for Measurement of Thickness of Sandwich Cores.

ADOPTION OF TENTATIVE AS STANDARD WITHOUT REVISION

Committee C-19 recommends that the Tentative Method of Tension Test in Flatwise Plane of Sandwich Constructions (**C 297 - 52 T**)[2] be approved for reference to letter ballot of the Society for adoption as standard without change.

The recommendations in this report have been submitted to letter ballot of the committee, the results of which will be reported at the Annual Meeting.[3]

ACTIVITIES OF SUBCOMMITTEES

Subcommittee I on Mechanical Properties of Basic Materials (George Gerard, chairman).—The present Tentative Method of Test for Tension Test in Flatwise Plane of Sandwich Constructions (C 297 - 52 T) has been reviewed and recommended for adoption as standard, as noted earlier in this report. Methods for flatwise compression, honeycomb core delamination, and core thickness measurement are being recommended for publication as tentative. The subcommittee is considering possible tests at elevated temperatures for core materials and possible tests for adhesives as they have particular requirements peculiar to sandwich constructions.

Subcommittee II on Mechanical Properties of Basic Sandwich Construction (J. P. Reese, chairman).—A method of edgewise compression test of flat sandwich construction has been reviewed and recommended for publication as tentative, as noted earlier in this report. Flatwise flexure test and peel test methods are being considered by the subcommittee.

Subcommittee III on Permanence, Durability, and Simulated Service (J. H.

*** Presented at the Fifty-eighth Annual Meeting of the Society, June 26–July 1, 1955.**

[1] The new tentatives appear in the 1955 Book of ASTM Standards, Part 3.

[2] **1952 Book of ASTM Standards, Part 4.**

[3] The letter ballot vote on these recommendations was favorable; the results of the vote are on record at ASTM Headquarters.

Gibbud, chairman) has devised an exposure testing program, making use of the facilities of the ASTM test sites, and several members are planning to place test panels for exposure this spring. The subcommittee is considering possible fatigue tests for sandwich constructions or core materials.

Subcommittee IV on Nomenclature and Definitions (Milton J. Rudick, chairman) is considering definitions of various sandwich core materials including a review of the present definitions (C 274 – 53).

This report has been submitted to letter ballot of the committee, which consists of 48 voting members; 33 members returned their ballots, of whom 32 have voted affirmatively and 0 negatively.

Respectfully submitted on behalf of the committee,

EDWARD W. KUENZI,
Chairman.

W. L. EMERSON,
Secretary.

REPORT OF COMMITTEE C-20

ON

ACOUSTICAL MATERIALS*

Committee C-20 on Acoustical Materials held two meetings during the past year: at Columbia University in New York City on December 1 and 2, 1954, and at ASTM Headquarters, Philadelphia, on May 17 and 18, 1955.

The committee now consists of 72 members, of whom 22 are classified as producers, 13 as consumers, 29 as general interest members, and 8 as consulting members.

Walton C. Clark, representing the Public Buildings Service of the General Services Administration, accepted the appointment to succeed Peter Chrzanowski as chairman of Subcommittee III on Maintenance.

NEW TENTATIVE

Committee C-20 recommends that the Methods of Test for Strength Properties of Prefabricated Architectural Acoustical Materials be accepted for publication as tentative as appended hereto.[1]

This recommendation has been submitted to letter ballot of the committee, the results of which will be reported at the Annual Meeting.[2]

ACTIVITIES OF SUBCOMMITTEES

Subcommittee I on Sound Absorption (H. J. Sabine, chairman).—A method of test of acoustic impedance and sound absorption by the tube method has been circulated for letter ballot with favorable results. The committee is continuing the study of discrepancies in the results of comparative tests of sound absorption by the reverberation chamber method. A draft of a box method of test is being prepared for information purposes.

Subcommittee II on Flame Resistance (Wallace Waterfall, chairman).—A draft of a test method for flame resistance based on Federal Specification SS-A-118b was circulated for letter ballot but failed to receive the necessary two-thirds affirmative vote. A revised draft is being prepared. The subcommittee is continuing its study of other existing or proposed methods applicable to acoustical materials.

Subcommittee III on Maintenance (W. C. Clark, chairman).—The investigation of methods of test of paintability, cleaning characteristics, and soiling tendencies is being continued.

Subcommittee IV on Application (L. F. Yerges, chairman).—A specification and test method for acoustical adhesives has been circulated for letter ballot of the subcommittee and has also been submitted to a task group of Committee D-14 on Adhesives for review and comments. A study of mechanical attachment problems will be undertaken.

Subcommittee V on Basic Physical Properties (W. A. Jack, chairman).—In addition to the set of five methods of test of strength properties being recom-

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*** Presented at the Fifty-eighth Annual Meeting of the Society, June 26–July 1, 1955.**

[1] The new tentative appears in the 1955 Book of ASTM Standards, Part 3.

[2] The letter ballot vote on these recommendations was favorable; the results of the vote are on record at ASTM Headquarters.

mended for publication as tentative, the subcommittee is continuing work on light reflectance and air flow resistance tests.

This report has been submitted to letter ballot of the committee, which consists of 64 voting members; 45 members returned their ballots, of whom 38 have voted affirmatively and 1 negatively.

Respectfully submitted on behalf of the committee,

H. A. Leedy,
Chairman.

H. J. Sabine,
Secretary.

REPORT OF COMMITTEE C-21

ON

CERAMIC WHITEWARE AND SIMILAR PRODUCTS*

Committee C-21 on Ceramic Whiteware and Similar Products held two meetings during the year: the first in Bedford Springs, Pa., on September 23, 1954, and the second in Cincinnati, Ohio, on April 25, 1955. The Executive Subcommittee met on the same days. The present voting membership consists of 45 producers, 9 consumers, and 19 general interest members, or a total of 73.

During the year, the Board of Directors approved a change in the title of Committee C-21 from "Ceramic Whiteware" to "Ceramic Whiteware and Similar Products," and a corresponding change was also made in the scope of the committee.

NEW TENTATIVES

Committee C-21 recommends that the following methods be accepted for publication as tentative as appended hereto:[1]

Method of Test for:

Linear Thermal Expansion of Fired Whiteware Products by the Dilatometer Method,
Water Absorption, Bulk Density, Apparent Porosity, and Apparent Specific Gravity of Fired Porous Whiteware Products,
Moisture Expansion of Fired Whiteware Products,
Impact Resistance of Ceramic Tableware,
Modulus of Rupture of Fired Cast or Extruded Whiteware Products, and
Sieve Analysis of Non-Plastic Pulverized Ceramic Materials.

REVISION OF TENTATIVE

The committee recommends that the Tentative Method of Test for Modulus of Rupture of Fired Dry-Pressed Whiteware Specimens at Normal Temperature (**C 328 - 53 T**)[2] be replaced by the Tentative Methods of Flexure-Testing Fired Dry-Pressed Ceramic Whiteware Specimens at Normal Temperature, as appended hereto.[3]

ADOPTION OF TENTATIVE AS STANDARD

The committee recommends that the Tentative Definitions of Terms Relating to Ceramic Whiteware (**C 242 - 54 T**)[4] be approved for reference to letter ballot of the Society for adoption as standard, with the exception of the terms "ball clay" and "calcine" which are to be continued as tentative.

STANDARDS OF OTHER COMMITTEES APPLICABLE TO CERAMIC WHITEWARE

The committee approves the use of the following method, under the jurisdiction of Committee E-1, as applied to ceramic whiteware:

Tentative Method of Test for 45-deg, 0-deg Directional Reflectance of Opaque Specimens by Filter Photometry (**E 97 - 53 T**), for measuring the apparent reflectance of glazed ceramic whiteware surfaces.

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* Presented at the Fifty-eighth Annual Meeting of the Society, June 26-July 1, 1955.

[1] The new tentatives appear in the 1955 Book of ASTM Standards, Part 3.

[2] 1953 Supplement to Book of ASTM Standards, Part 3.

[3] The new tentative appears in the 1955 Book of ASTM Standards, Part 3.

[4] 1954 Supplement to Book of ASTM Standards, Part 3.

The recommendations in this report have been submitted to letter ballot of the committee, the results of which will be reported at the Annual Meeting.[5]

ACTIVITIES OF SUBCOMMITTEES

Subcommittee I on Nomenclature (A. S. Watts, chairman) held four meetings and circulated five questionnaires during the year in an effort to reach agreement on the wording of definitions now tentative. Such agreement has been reached on 58 definitions; these are referred to earlier in this report.

The subcommittee has also developed definitions for 29 additional terms which it believes will soon be ready for submission to the members of Committee C-21 for approval as tentative.

Subcommittee II on Tests and Specifications (Van E. Campbell, chairman). —Subsection A2 on Non-Plastics (D. E. Walsh, chairman) prepared the proposed Tentative Method of Test for Sieve Analysis of Non-Plastic Pulverized Ceramic Materials referred to earlier in this report.

Subsection A3 on Titanate and Zirconate (W. J. Baldwin, chairman) held one meeting at which time a round-robin test program was organized to evaluate ceramic and electrical properties of barium titanate dielectrics. Some of these tests have been completed.

Subsection C1 on Fundamental Properties (W. C. Mohr, chairman) prepared six new tentatives and one revised tentative which have been submitted to letter ballot of Committee C-21. Subsection C1 has also approved two additional methods which are now to be submitted to ballot of Subcommittee II, namely, Method of Test for Thermal Conductivity of Whiteware Ceramics and Method of Testing Compressive (Crushing) Strength of Fired Whiteware Materials.

Subcommittee III on Research (H. Z. Schofield, chairman).—Activities during the year were concerned with research into methods of testing properties of raw materials and ceramic whiteware products.

The group on measurement of subsieve particle size, under the direction of A. Kent Smalley, completed its round-robin study. The results are considered ready for submittal to Subcommittee II.

A group is being formed on method of determining modulus of rupture, and further groups now seem desirable to study methods of determining resistance of overglaze colors to detergents, degree of vitrification (water absorption), and brittleness.

This report has been submitted to letter ballot of the committee, which consists of 73 voting members; 48 members returned their ballots, of whom 46 have voted affirmatively and 1 negatively.

Respectfully submitted on behalf of the committee,

C. J. KOENIG,
Chairman.

A. J. GITTER,
Secretary.

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[5] The letter ballot vote on these recommendations was favorable; the results of the vote are on record at ASTM Headquarters.

REPORT OF COMMITTEE C-22

ON

PORCELAIN ENAMEL*

Committee C-22 on Porcelain Enamel held two meetings during the year: the first on October 19–20, 1954, as guests of the Westinghouse Electric Corp., Columbus, Ohio, and the second on February 2 and 3, 1955, as guests of the General Electric Co., Appliance Park, Louisville, Ky.

During the past year, four new members were added to the committee and two members have been lost, one through resignation and one through death. Two corporate member representatives (one deceased) have been replaced. At present the committee consists of 43 members, of whom 36 are voting members, with 19 classified as producers, 6 as consumers, and 11 as general interest members.

During the year the subcommittee organization of the committee was modified by the elimination of Subcommittee III on Tests and Specifications and the addition of two new subcommittees (Subcommittee IV on Materials and Subcommittee V on Finished Products). To simplify subcommittee designations, the numerical designation of the Subcommittee on Education was changed from IV to III. The office of Second Vice-Chairman was created by the committee during the year, and Ralph L. Bisbee was elected to the office until the next regular election.

SUGGESTED METHOD

The committee recommends that the Method of Test for Set Characteristics of Porcelain Enamel Clays (Slump Method) be published as a suggested method, as appended hereto.[1]

PROPOSED METHODS TO BE PUBLISHED AS INFORMATION

The committee recommends that the Proposed Method of Test for Determining Sag Resistance of Steel Sheets for Porcelain Enameling be published as information only, as appended hereto.[2]

NEW TENTATIVES

The committee recommends that the following method and classification be accepted for publication as tentative as appended hereto:[3]

Tentative Method of Test for Fusion Flow of Porcelain Enamel Frits—Flow-Button Method, and

Tentative Classification of Water Used in Milling of Porcelain Enamel.

REVISION OF TENTATIVES

The committee recommends revisions of the following tentatives as indicated:

Tentative Definitions of Terms Relating to Porcelain Enamels (C 286 – 51 T):[4]

The revised version is appended hereto.[5] The recommended revision is the result of four years of careful study during which time approximately 40 per cent of the definitions were revised and brought up to date. A number of additional definitions have been added.

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* Presented at the Fifty-eighth Annual Meeting of the Society, June 26–July 1, 1955.

[1] See p. 429.

[2] See p. 431.

[3] The new tentatives appear in the 1955 Book of ASTM Standards, Part 3.

[4] 1952 Book of ASTM Standards, Part 3.

[5] The revised tentative appears in the 1955 Book of ASTM Standards, Part 3.

Tentative Method of Test for 45-deg Specular Gloss of Porcelain Enamels (C 346 - 54 T):[6]

Title.—Change "Porcelain Enamels" to read "Ceramic Materials."

Section 1.—Change to read as follows:

> 1. This method of test is intended for determining specular gloss of porcelain enameled and ceramic whiteware specimens, but may be applicable to other specimens having similar reflection characteristics. The method may be used to compare the gloss of porcelain enameled and ceramic whiteware specimens or to provide an index of acid or abrasion resistance by measurement of gloss loss.

This revision has been made at the request of Committee C-21 on Ceramic Whiteware in order to make the method equally suitable for the use of either Committee C-21 or Committee C-22.

ADOPTION OF TENTATIVE AS STANDARD WITHOUT CHANGE

The committee recommends that the Tentative Method of Test for Adherence of Porcelain Enamel and Ceramic Coatings to Sheet Metal (**C 313 - 53 T**)[7] be approved for reference to letter ballot of the Society for adoption as standard without change.

TENTATIVES CONTINUED WITHOUT REVISION

The committee recommends that the following be continued as tentatives without revision:

Tentative Methods of Test for:

Impact Resistance of Porcelain Enameled Utensils (**C 284 - 51 T**), and

Warpage of Porcelain Enameled Flatware (**C 314 - 53 T**).

The recommendations appearing in this report have been submitted to letter ballot of the committee, the results of which will be reported at the Annual Meeting.[8]

ACTIVITIES OF SUBCOMMITTEES

Subcommittee I on Research (J. J. Canfield, chairman) has ten problems under investigation. Five bibliographic reports related to the behavior and testing of porcelain enamel have been prepared during the year and submitted to Subcommittees IV and V.

Subcommittee II on Nomenclature (E. E. Howe, chairman) is continuing its review of the Tentative Definitions of Terms Relating to Porcelain Enamels (C 286 - 51 T). Approximately one third of this work has been completed and is included in a recommended revision of the tentative which is appended to this report.[5]

Subcommittee III on Education (L. S. O'Bannon, chairman) is continuing its work of properly publicizing the work of Committee C-22. Its work has been quite successful not only in the technical press but in the nontechnical press as well.

Subcommittee IV on Materials (W. A. Deringer, chairman) during the past year has submitted to Committee C-22 two suggested test methods, one proposed tentative test method, and one proposed tentative material classification. The subcommittee is presently working on nine projects.

Subcommittee V on Finished Products (J. C. Richmond, chairman) has proposed one modification of an existing tentative and is at present working on eleven projects.

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[6] 1954 Supplement to Book of ASTM Standards, Part 3.

[7] 1953 Supplement to Book of ASTM Standards, Part 3.

[8] The letter ballot vote on these recommendations was favorable; the results of the vote are on record at ASTM Headquarters.

This report has been submitted to letter ballot of the committee, which consists of 36 voting members; 29 members returned their ballots, of whom 26 have voted affirmatively and 0 negatively.

Respectfully submitted on behalf of the committee,

W. N. HARRISON,
Chairman.

G. H. SPENCER-STRONG,
Secretary.

APPENDIX I

SUGGESTED METHOD OF TEST FOR SET CHARACTERISTICS OF PORCELAIN ENAMEL CLAYS (SLUMP METHOD)[1,2]

Scope

1. (*a*) This method is intended to measure, by means of a slump test on a slip consisting of clay, electrolytes, and water, the relative "set" characteristic imparted by the clay. The slump measurement may be used to indicate "set" behavior of different enamel clays or the uniformity of a single clay from lot to lot.

(*b*) Constant additions of electrolytes may be selected by the operator to approximate a clay-electrolyte combination and proportion associated with his enameling operation. A constant water addition may be established to obtain a desirable range of slump measurements for the same or different clays under constant electrolyte conditions.

Apparatus

2. (*a*) *Mixer.*—A No. 33 Hamilton-Beach mixer, or equivalent, with an 18-8 stainless steel cup.

(*b*) *Slump Tester.*—An Irwin Slump Tester, a device whereby the slip contained in a 2.562 in. long by 2.468 in. OD by 1.875 in. ID brass cylinder is instantly and uniformly released around the base of the cylinder and thereby allowed to flow freely over a smooth, flat plate. The device is normally actuated by the release of a heavy counterweight attached to the cylinder (see Fig. 1).

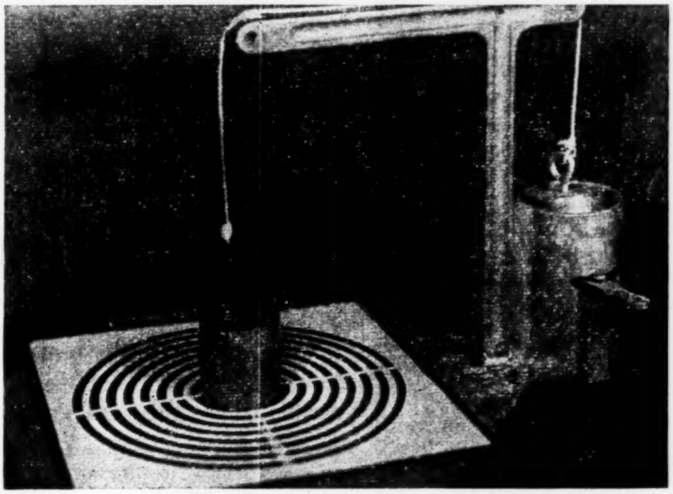

FIG. 1.—Slump Tests.

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[1] This suggested method has no official status in the Society, but is published as information only. Comments are solicited.

[2] Submitted by Subcommittee IV on Raw Materials and Materials in Process, of the ASTM Committee C-22 on Porcelain Enamel.

Sample

3. A representative sample of the clay to be tested shall be obtained by approved methods, mixed thoroughly, and reduced by quartering to no less than 100 g.

Procedure

4. (*a*) Add to the dry cup a constant quantity of cold distilled water, preferably measured from a calibrated flask. Add the selected electrolytes in standardized quantities (Note) to the cup and blunge 1 min.

NOTE: *Example.*—Add 100 ml of water. Then add 10.7 g of hydrated borax, 3.6 g of magnesium carbonate, and 1.7 g of sodium nitrite.

(*b*) Add 100.0 g of finely pulverized clay sample and allow to settle in the cup; then immediately begin blunging for a 10-min period.

(*c*) Set up the slump tester, being sure that the plate and cylinder are dry, the plate is level, and that the cylinder is centered over the plate and hanging plumb (see Fig. 1).

(*d*) On completion of blunging, tap the cup several times to remove some of the entrapped air and then pour the slip slowly into the cylinder until full. Work a spatula up and down several times in the contained slip; then level the surface for the determination.

(*e*) Sharply trip the counterweight and measure the diameter of slump at three positions. Two measurements in agreement shall to be considered as the correct measurement.

APPENDIX II

PROPOSED METHOD OF TEST FOR DETERMINING SAG RESISTANCE OF STEEL SHEETS FOR PORCELAIN ENAMELING[1, 2]

This is a proposed method and is published as information only. Comments are solicited and should be addressed to the American Society for Testing Materials, 1916 Race St., Philadelphia 3, Pa.

Scope

1. This method covers a procedure for evaluating the sagging characteristics of steel sheets used for porcelain enameling applications. Sagging is defined as permanent distortion by downward bending of insufficiently supported spans of an article during enamel firing at temperatures above about 1400 F. This bending is due to the inability of the steel to support its own weight at these temperatures and is irreversible.

Apparatus

2. (*a*) *Specimen Support.*—The rack or frame for supporting the specimen during firing shall be constructed of heat-resistant alloy rods $\frac{1}{4}$ in. in diameter. The dimensions of the rack shall be such that the distance between the horizontal supports for the specimen is 10 in. from center to center. The two supports are made of refractory tubing commonly used for insulating thermocouple wires and are suspended from the frame by 28 B & S gage chromel wire. The vertical distance from the support to the point of contact with the frame shall be not less than 4 in. Other dimensions of the rack can be varied to suit individual requirements. A satisfactory firing rack is illustrated in Fig. 1.

(*b*) *Furnace.*—The characteristics of the furnace used for firing the specimens have very important influences on the test results. Because the characteristics of commercial laboratory furnaces vary considerably, the results obtained in one laboratory cannot be directly compared to those obtained in another laboratory, unless furnaces with identical firing rates and temperature controls are used. In general, the furnace should have sufficient heating capacity to heat the specimen from room temperature to the firing temperature (1575 F) in about 2 min and to maintain the temperature of the entire specimen within ±5 F of the firing temperature for 8 min. Preferably, the furnace should be electrically fired and should be equipped with proportioning controls to prevent "overriding" the firing temperature.

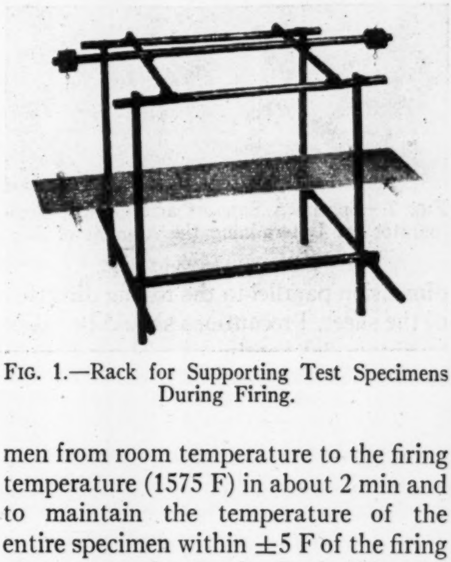

FIG. 1.—Rack for Supporting Test Specimens During Firing.

(*c*) *Measuring Device.*—Means shall be provided for supporting the specimen during the sag determination on two

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[1] This proposed method is under the jurisdiction of ASTM Committee C-22 on Porcelain Enamel.

[2] Published as information, June, 1955.

parallel, horizontal, knife-edge bars spaced 10 in. apart. Apparatus shall be provided for measuring the deflection of the center of the specimen before and after firing by such means as an optical micrometer slide comparator or an attached micrometer screw device. Figure 2 illustrates one type of support used in conjunction with an optical comparator.

Test Specimens

3. Three test specimens, each $2\frac{1}{8}$ in. wide and 12.00 ± 0.01 in. long, shall be sheared from the center portion of the sheet being investigated with the 12-in. dimension parallel to the rolling direction of the sheet. Precautions should be taken to obtain flat specimens with no bow or other deviation from flatness. The specimens should not be flattened by cold working. After shearing, the specimens shall be milled to a width of 2 ± 0.003 in., $\frac{1}{16}$ in. being milled from each edge to remove the shearing burr and to make the sides of the specimen parallel. Milling burrs shall be removed with a fine-cut file (Note). Eight 0.052-in. diameter holes (No. 55 drill) shall be drilled in the specimen to receive the U-shaped wires (22 B & S gage) that hold the specimen to the supports. The location of the holes is shown in Fig. 3.

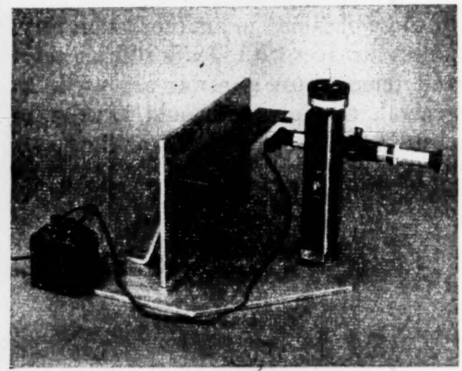

FIG. 2.—Specimen Support and Optical Comparator for Determining the Amount of Sag.

NOTE.—Burrs on the edges tend to increase the sag resistance of the specimen and thereby lead to erroneous sag values.

Preparation of Test Specimens

4. (*a*) Clean, pickle, and neutralize the test specimens by means of established good enameling shop practices. Coat each specimen with a standard ground coat enamel to yield a coating weight of 17.0 to 20.0 g per square foot of sheet surface (one side). After drying, brush the enamel from the areas of the underside of the specimens that will be in contact with the supports during firing.

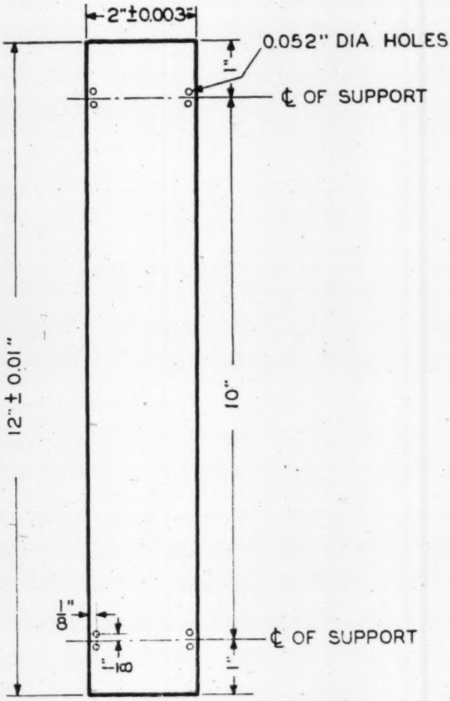

FIG. 3.—Specimen for Sag Test.

(*b*) Place each specimen on the measuring device and measure and record the deflection at the center. Discard specimens with excessive bow and obtain new specimens.

Procedure

5. (*a*) Place one of the test specimens on the supports of the firing rack, which

shall previously have been dusted with clay to prevent adherence between the specimen and the support. Insert small U-shaped wires through the holes in the specimen as illustrated in Fig. 1.

(*b*) Place the firing rack and specimen in a hot furnace, the controls of which are set so that the specimen will be heated to 1575 F in about 2 min. Check this heating cycle periodically by means of thermocouples attached to dummy specimens. After a total time of 10 min in the furnace, with about 8 min at 1575 F, remove the specimen and rack from the furnace and permit it to cool to room temperature in still air.

(*c*) When the specimen is cold, place it on the supports of measuring device and measure its deflection.

(*d*) Test the other two specimens (Section 3) in the same way.

Report

6. Report the difference between the deflection after firing (Section 5) and the deflection before firing (Section 4) in hundredths of an inch as the sag of the specimen. Average the sag values for the three specimens from the same sheet and report the average as the sag value of the sheet being investigated.

REPORT OF COMMITTEE D-1

ON

PAINT, VARNISH, LACQUER, AND RELATED PRODUCTS*

Committee D-1 on Paint, Varnish, Lacquer, and Related Products held two meetings during the year. On June 14 to 16, 1954, the committee met in Chicago, Ill., in connection with the 1954 Annual Meeting of the Society. The spring meeting of the committee, at Roanoke, Va., was held on February 21 to 24, 1955, in conjunction with Committees E-12 on Appearance and D-16 on Industrial Aromatic Hydrocarbons and Related Products.

At the June, 1954, meeting, E. B. Fitzgerald, Marshall Laboratory of E. I. du Pont de Nemours & Co., Inc., presented a well illustrated talk on "The Photochemical Deterioration of Alkyd Resin Enamels." The paper was a companion paper to the one presented by Roger Saur at the February, 1954 meeting.[1]

At the February, 1955 meeting, W. J. Youden, National Bureau of Standards, presented a paper on "Statistical Design in the Development of Test Methods." At a special dinner attended by members of Committee D-1 and Committee E-12 an illustrated lecture on "Depth Perception in Color Photography" was presented by Ralph M. Evans, Eastman Kodak Co.

At the June, 1955 meeting there will be presented a paper on "The Importance of Test Methods for Controlling the Quality of Paints Used by the United States Navy," with particular emphasis on the work of Committee D-1.

During the past year, steps were taken for the organization of a new Subcommittee on Putty, Glazing, and Caulking Compounds.

The number of standards which have been jointly approved by both the Federation of Paint and Varnish Production Clubs and the ASTM cooperating through the Joint Committee remains at 61, with 10 additional ASTM standards and tentatives being considered by the Federation. Two methods which originated with the Federation are being considered within Committee D-1.

The Committee on Inter-Committee Relations, composed of Committee D-1 representatives on other ASTM technical committees, is continuing to maintain close contact with those committees whose activities are of interest to Committee D-1. In the last year, representatives of Committee D-1 have been appointed to Committee C-15 on Manufactured Masonry Units, Subcommittee IX on Bituminous Emulsions of Committee D-8 on Bituminous Waterproofing and Roofing Materials, and Subcommittee 21 on Metalware Laboratory Apparatus of Committee E-1 on Methods of Testing.

During the year, the committee approved an amendment to the Regulations Governing Committee D-1 to define the scope and status of methods that are published as information only.

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* Presented at the Fifty-eighth Annual Meeting of the Society, June 26–July 1, 1955.

[1] Roger L. Saur, "Photochemical Degradation of Automobile Lacquers," ASTM Bulletin, No. 207, July, 1955, p. 61 (TP133).

The committee approved a recommendation of the Advisory Committee for the establishment of a publications committee to act upon the statements of work suitable for publication, to be provided by the subcommittee chairmen.

At the June, 1954, meeting, the committee voted unanimously to elect F. H. Lang as the first Honorary Member of Committee D-1. At the February, 1955, meeting, it was voted to elect E. F. Hickson as the second Honorary Member of Committee D-1.

RECOMMENDATIONS ACCEPTED BY THE ADMINISTRATIVE COMMITTEE ON STANDARDS

During 1954, Committee D-1 presented to the Society through the Administrative Committee on Standards the following recommendations:

Tentative Method of Test for:

Effect of Household Staining Agents on Applied Nitrocellulose Clear and Pigmented Finishes (**D 1308 - 54 T**), and
Nonvolatile Matter of Lacquer Solvents and Diluents (**D 1353 - 54 T**).

These recommendations were accepted by the Standards Committee on May 18, 1954, and December 22, 1954, respectively, and the new methods appear in the January, 1955, compilation of ASTM Standards on Paint, Varnish, Lacquer, and Related Products.

PROPOSED METHODS TO BE PUBLISHED AS INFORMATION

The committee submits for publication as information the Proposed Method of Test for Nonvolatile Content of Heat-Unstable Resin Solutions by Use of Foil and the Proposed Methods for Analysis of Polyvinyl Butyral, as appended hereto.[2]

NEW TENTATIVES

The committee recommends for publication as tentative the following eight methods of test and one recommended practice, as appended hereto:[3]

Tentative Methods of:

Test for Spectrophotometric Diene Value,
Test for No-Smear Time of Traffic Paint,
Test for Fire Retardency of Paints (Cabinet Method),
Test for Fire Retardency of Paints (Stick and Wick Method),
Test for Alcohol in Methyl Isobutyl Ketone,
Test for Permanganate Time of Lacquer Solvents, and Diluents,
Test for Water in Lacquer Solvents and Diluents,
Method for Measurement of Color Difference with the Hunter Color Difference Meter, and
Recommended Practice for Reporting Particle Size Characteristics of Pigments.

REVISION OF TENTATIVES

Committee D-1 recommends revision of the following three methods and two specifications and their continuation as tentative:

Tentative Methods of Test for:

Asphalt Emulsions for Use as Protective Coatings for Metal (**D 1010 - 49 T**)[4] jointly with Committee D-8, revised as appended hereto.[5]
Calculating Small Color Differences from Data Obtained on the Hunter Multipurpose Reflectometer (**D 1260 - 53 T**),[6] revised as appended hereto.[5]
Flash Point of Volatile Flammable Materials by Tag Open-Cup Apparatus (**D 1310 - 54 T**),[7] revised as appended hereto.[5]

Tentative Specifications for:

Dehydrated Castor Oil (**D 961 - 53 T**),[6] revise as follows:

Section 2.—In the table change the requirements for specific gravity to the basis of 25/25C to read as follows:

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[2] See pp. 442 and 445.

[3] The new tentatives appear in the 1955 Book of ASTM Standards, Part 4.

[4] 1952 Book of ASTM Standards, Part 4.

[5] The revised tentative appears in the 1955 Book of ASTM Standards, Part 4.

[6] 1953 Supplement to Book of ASTM Standards, Part 4.

[7] 1954 Supplement to Book of ASTM Standards, Part 4.

	Unbodied		Bodied	
	Min	Max	Min	Max
Specific gravity, 25/25 C..............	0.926	0.937	0.944	0.966

Section 3.—Omit Paragraph (*b*) and reletter the other paragraphs accordingly.

Methyl Isobutyl Ketone **(D 1153 – 51 T)**,[4] revised as appended hereto.[5]

TENTATIVE REVISION OF STANDARD

The committee recommends that the Standard Definitions of Terms Relating to Paint, Varnish, Lacquer, and Related Products **(D 16 – 52)**[3] be revised by the addition of the following new tentative definition of latex paint:

> *Latex Paint.*—One containing a stable aqueous dispersion of synthetic resin, produced by emulsion polymerization, as the principal constituent of the binder. Modifying resins may also be present.

REVISIONS OF STANDARDS AND REVERSION TO TENTATIVE

The committee recommends that the Standard Specifications for Acetone **(D 329 – 33)**[4] and the Standard Methods of Test for Tinting Strength of White Pigments **(D 332 – 36)**[4] be revised as appended hereto and reverted to tentative status.[5]

ADOPTION OF TENTATIVES AS STANDARDS

Committee D-1 recommends that the following seven tentatives be approved for reference to letter ballot of the Society for adoption as standard without change:

Tentative Specifications for:

Wood to be Used as Panels in Weathering Tests of Paints and Varnishes **(D 358 – 51 T)**,[4]

High Gravity Glycerine **(D 1257 – 53 T)**,[6]

Tentative Methods of:

Sampling and Testing High-Gravity Glycerine **(D 1258 – 53 T)**,[6]

Test for Solvent Tolerance of Amine Resins **(D 1198 – 52 T)**,[4]

Test for Residual Odor of Lacquer Solvents and Diluents **(D 1296 – 53 T)**,[6]

Chemical Analysis of White Lead Pigments **(D 1301 – 53 T)**, replacing Sections 6 to 18 of the General Methods D 34, and

Tentative Single and Multi-Panel Forms for Recording Results of Exposure Tests of Paints **(D 1150 – 51 T)**.[4]

REVISIONS OF STANDARDS, IMMEDIATE ADOPTION

The committee recommends for immediate adoption revisions in the following nine standards, and accordingly asks for the necessary nine-tenths affirmative vote at the Annual Meeting in order that the revisions may be referred to letter ballot of the Society:

Specifications for Raw Tung Oil (D 12 – 48),[4] revise as follows:

Section 2.—Change the requirements for specific gravity to read as follows:

Specific Gravity, 25/25C.... 0.935[a] to 0.938

[a] For American grown tung oil the minimum specific gravity may be as low as 0.933.

Specifications for Raw Linseed Oil (D 234 – 48),[6] revise as follows:

Section 2.—Change the requirements for specific gravity to read as follows:

Specific Gravity, 25/25C.... 0.926 to 0.931

Specifications for Boiled Linseed Oil (D 260 – 48),[4] revise as follows:

Section 2.—Change the requirements for specific gravity to read as follows:

Specific Gravity, 25/25C.... 0.926 to 0.940[a]

[a] When a high viscosity type of boiled linseed oil is required, the specific gravity shall be not less than 0.932.

Specifications for Oiticica Oil (Permanently Liquid) (D 601 – 46), revised as appended hereto.[8]

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[8] The revised standard appears in the 1955 Book of ASTM Standards, Part 4.

Specifications for Dry Bleached Shellac (**D 207 – 49**),[4] revise as follows:

Title.—Change to read "Dry Bleached Lac."

Section 1.—In line 2 change "shellac" to "lac."

Note.—Change to read as follows:

Note.—Dry bleached lac is also known as "bone-dry," "vac-dry," or "kiln-dry" bleached lac. The refined grade is bleached lac from which practically all the wax and insoluble matter has been removed during the process of manufacture.

Section 2.—In line 1 change "shellac" to "lac."

Specifications for Orange Shellac and Other Lacs (**D 237 – 48**),[4] revise as follows:

Section 2.—Delete Note 1 in its entirety.

Table I.—In line headed "Iodine number, max," insert under Grade A, "15," under Grade B, "15," under Grade C, "15," and under Type II, change "18" to "15."

Below line reading "Ash, max, per cent," insert the following: Requirements for Rosin. Add for Type I grade A, "none," for grade B, "none," for grade C, "none," and for Type II, "none."

Specifications for Shellac Varnishes (**D 360 – 51**),[4] revise as follows:

Section 2.—In line 4 change "shellac" to "lac."

Section 5.—In line 5 of second paragraph of Note, change "shellac" to "lac."

Section 6.—In the table of requirements opposite line reading "Iodine number, max," insert "15" under Grade A.

At bottom of table insert the following requirements under Bleached Lac, both regular and refined:

Acid number....	When specified the acid number shall be not greater than that agreed upon by the purchaser and seller.

Note.—In line 1 change "shellac" to "lac."

Method of Test for Consistency of Exterior House Paints and Enamel-Type Paints (**D 562 – 47**),[4] revised as appended hereto.[8]

Method of Test for No-Pick-Up Time of Traffic Paint (**D 711 – 52**),[4] revised as appended hereto.[8]

WITHDRAWAL OF STANDARDS

The committee recommends the withdrawal of the Standard Specifications for Pure Linseed Oil Putty for Glazing (**D 317 – 33**) which are obsolete.

The committee also recommends the withdrawal of the Standard Method of Test for Daylight 45-deg, 0-deg Luminous Directional Reflectance of Paint Finishes (**D 771 – 47**) in favor of the Tentative Method of Test for 45-Deg, 0-Deg Directional Reflectance of Opaque Specimens by Filter Photometry (**E 97 – 53 T**).

REAPPROVAL OF STANDARDS

Committee D-1 recommends reapproval of the following six standards which have been published for six years or longer without revision:

Standard Method of Test for:

Nitrocellulose Clear Lacquers and Lacquer Enamels (**D 333 – 40**),
Spectral Characteristics and Color of Objects and Materials (**D 307 – 44**)

Standard Specifications for:

Industrial 90 Benzene for Use in Paint, Varnish, Lacquer, and Related Products (**D 361 – 36**),
Industrial Grade Toluene for Use in Paint, Varnish, Lacquer, and Related Products (**D 362 – 36**),
Tricresyl Phosphate (**D 363 – 49**), and
Industrial Grade Xylene or Solvent Naphtha for Use in Paint, Varnish, Lacquer, and Related Products (**D 364 – 36**).

JOINT APPROVAL OF TENTATIVE

The Tentative Method of Test for Copper Corrosion by Petroleum Products (Copper Strip Test) (**D 130 - 54 T**),[7] developed by Committee D-2 on Petroleum Products and Lubricants, is recommended for approval. This action is taken on the recommendation of the D-1 Subcommittee V on Volatile Solvents for Organic Protective Coatings and Subcommittee XXV on Cellulosic Coatings and Related Materials.

The recommendations in this report have been submitted to letter ballot of the committee, the results of which will be reported at the Annual Meeting.[9]

TENTATIVES CONTINUED WITHOUT REVISION

The committee recommends that the following six tentatives be continued as tentative without revision:

Tentative Methods of:

Test for Ester Value of Tricresyl Phosphate (**D 268 - 49 T**),
Test for Specular Gloss (**D 523 - 53 T**),
Test for Asphalt-Base Emulsions for Use as Protective Coatings for Built-Up Roofs (**D 1167 - 51 T**),
Test for Temperature-Change Resistance of Clear Nitrocellulose Lacquer Films Applied to Wood (**D 1211 - 52 T**),
Test for Nonvolatile Content of Resin Solutions (**D 1259 - 53 T**), and

Tentative Recommended Practice for:

Operating Light and Water Exposure Apparatus (Carbon-Arc Type) for Testing Paint, Varnish, Lacquer, and Related Products (**D 822 - 46 T**).

ACTIVITIES OF SUBCOMMITTEES

Subcommittee II on Drying Oils (D. S. Bolley, chairman) prepared the proposed Tentative Method of Test for Diene Value of Dehydrated Castor Oil by Spectrophotometric Analysis. The subcommittee also recommended immediate adoption of the proposed revisions of temperatures and limits for specific gravity (from 15.5/15.5 C to 25/25 C) in the Specifications for Raw Tung Oil (D 260 - 48), for Raw Linseed Oil (D 234 - 48), for Bodied Linseed Oil (D 260 - 48), and for Dehydrated Castor Oil (D 961 - 53 T).

Subcommittee III on Bituminous Emulsions (R. H. Cubberley, chairman) prepared a revision of the Methods of Testing Asphalt Emulsions for Use as Protective Coatings for Metals (D 1010-49 T) in cooperation with Committee D-8 on Bituminous Waterproofing and Roofing Materials. Liaison is being effected between Subcommittee III and Committee D-8 on the above method and also on Tentative Methods of Testing Asphalt-Base Emulsions for Use as Protective Coatings for Built-Up Roofs (D 1167 - 51 T).

Subcommittee IV on Traffic Paint (W. G. Vannoy, chairman) prepared the proposed revision of Standard Method of Test for No-Pick-Up Time of Traffic Paint (D 711 - 52) which includes an alteration in wet film thickness and a more flexible specification for the test wheel. A proposed Tentative Method of Test for No-Smear-Time of Traffic Paint has been prepared. An article on "Beaded Traffic Line Paint" by S. Werthan appeared in the December, 1954, issue of the ASTM BULLETIN.[10] Cooperative work is continuing on the development of a suitable accelerated durability test for traffic paint and a glass bead reflectance test.

Subcommittee V on Volatile Solvents for Organic Protective Coatings (M. B. Chittick, chairman) is continuing its work with particular emphasis on distillation procedures and evaporation rates.

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[9] The letter ballot vote on these recommendations was favorable; the results of the vote are on record at ASTM Headquarters.

[10] ASTM BULLETIN, No. 202, December, 1954, p. 59 (TP 245).

Subcommittee VI on Definitions (G. G. Sward, chairman) prepared the proposed definition of "latex paint" as a tentative revision of the Definitions of Terms Relating to Paint, Varnish, Lacquer, and Related Products (D 16 – 52).

Subcommittee VII on Accelerated Tests for Protective Coatings (H. D. Pharo, chairman) recommended that the Tentative Specifications for Wood to be Used as Panels in Weathering Tests of Paints and Varnishes (D 358 – 51 T) and Tentative Single and Multi-Panel Forms for Recording Results of Exposure Tests of Paints (D 1150 – 41 T) be adopted as standard. A revision is being completed of the Tentative Recommended Practice for Operating Light and Water Exposure Apparatus (Carbon-Arc Type) for Testing Paint, Varnish, Lacquer, and Related Products (D 822 – 46 T). Cooperative work is being continued on the preparation of test panels for salt spray and water immersion tests Methods are also being prepared for the preparation of panels of tin, glass, fabric, and concrete. Seven laboratories are cooperating on a water fog test. Preliminary tests have been completed on two methods which appear to produce yellowing of white interior paints in a manner consistent with indoor exposure. Information is being requested from appliance manufacturers on test methods for chemical resistance of appliance enamels.

Subcommittee VIII on Methods of Chemical Analysis of Paint Materials (W. H. Madson, chairman) recommended that the Tentative Methods for Chemical Analysis of White Lead Pigments (D 1301 – 53 T) be adopted as standard. The subcommittee is considering the revision of the Standard Methods of Chemical Analysis of White Linseed Oil Paints (D 215 – 41). The conductivity test described in Tentative Methods for Chemical Analysis of Blue Pigments (D 1135 – 50 T) will be investigated for adaptation to iron oxide pigments.

Subcommittee IX on Varnish (J. C. Weaver, chairman) is making an extensive revision of the Standard Specifications for Liquid Paint Driers (D 600 – 43), and is completing its work on methods of test for abrasion resistance of clear floor coatings. Work is being continued on color of transparent liquids, skinning tests, and rosin content. The group on viscosity of transparent liquids will be reactivated to study discrepancies between sets of standards of Gardner-Holdt bubble tubes. Papers on the experimental work of the groups on acid value and on abrasion resistance of clear floor coatings are being prepared.

Subcommittee X on Optical Properties (M. P. Morse, chairman) prepared the proposed Tentative Method for Measurement of Color Difference with the Hunter Color Difference Meter. The subcommittee also recommended the revisions of Method for Calculating Small Color Differences from Data Obtained on the Hunter Multipurpose Reflectometer (D 1260 – 53 T) and Method of Test for Tinting Strength of White Pigments (D 332 – 36). Methods are being drafted for color difference measurements for the General Electric Spectrophotometer, the Beckman Spectrophotometer, the Color Eye Colorimeter, and the Colormaster Colorimeter. Work is continuing on reproducibility of various types of goniophotometers, on the effect of changes in source aperture spread on the values obtained from glossmeters, on measuring the hiding power of nonchromatic paints, and on the correlation of instrumental results with visual ratings of gloss of clear finishes over wood.

Subcommittee XI on Resins (C. F. Pickett, chairman) recommended that the Tentative Specifications for High-Gravity Glycerine (D 1257 – 53 T), Tentative Method of Test for Solvent Tolerance of Amine Resins (D 1198 – 52 T), and Tentative Methods of Sampling and Testing High-Gravity Glycerine (D 1258 – 53 T) be adopted as standard. The possibility of extending a new foil method to include heat-sensitive resins is being investigated. The Proposed Method of Test for Nonvolatile Content of Heat-Unstable Resin Solutions by the Foil Method, and the Proposed Methods for Analysis of Polyvinyl Butyral are recommended for publication as information only.[2] Work is continuing on softening points, the determination of polyhydric alcohols in alkyds, and color on ester formation between high-gravity glycerine and phthalic anhydride.

Subcommittee XII on Latex and Emulsion Paints (P. T. Howard, chairman) plans cooperative tests on washability of latex paints, including unmodified and modified styrenebutadiene, acrylic, and polyvinylacetate types. Work is continuing on efflorescence, freeze-thaw stability, and package stability. The Philadelphia Paint and Varnish Production Club has signified its desire to cooperate with the subcommittee's investigation of weathering of latex paints. Efforts are continuing to develop test methods for various aspects of stability in the container.

Subcommittee XIII on Shellac (C. C. Hartman, chairman) prepared the proposed revisions of Specifications for Dry Bleached Shellac (D 207 – 49), for Orange Shellac and Other Lacs (D 237 – 48), and for Shellac Varnishes (D 360 – 51). Considerable progress was made in the project of development of international specifications at the meeting of Technical Committee 50 on Lac of the International Organization for Standardization at which the subcommittee was represented.

Subcommittee XV on Specifications for Pigments, Dry and in Oil (C. L. Crockett, chairman) prepared the proposed Tentative Recommended Practice for Reporting the Particle Size Characteristics of Pigments. Progress was reported in the work on leafing properties of aluminum and on the flocculation resistance and crystal stability of copper phthalocyanine blue pigments.

Subcommittee XVI on Printing Inks (M. C. Rogers, chairman) has in preparation proposed Tentative Methods of Test for Specific Gravity of Paste Printing Inks, and for Specific Gravity of Free Flowing Printing Inks.

Subcommittee XVII on Flash Point (A. L. Brown, chairman) prepared the proposed revision of the Tentative Method of Test for Flash Point of Volatile Flammable Materials by Tag Open-Cup Apparatus (D 1310 – 54 T). Work is continuing, in cooperation with the Bureau of Explosives Laboratory of the Association of American Railroads, on the development of a method for determining the flash point of viscous materials using a modified Tag Open-Cup Apparatus with a rotating cup and a fixed thermometer.

Subcommittee XVIII on Physical Properties of Materials (E. J. Dunn, Jr., chairman) prepared the two proposed Tentative Methods of Test for Fire Retardency of Paints by the Cabinet Method, and by the Stick and Wick Method. It also recommended immediate adoption as standard of the proposed revision of the Method of Test for Consistency of Exterior House Paints and Enamel-Type Paints (D 562 – 47). A method covering the procedure of measurement of the film thickness of films on a nonmagnetic base is being prepared in two parts covering the

Filmeter and the Gardner Gage. Work will be initiated on materials to be tested with Mikroknife, Adherometer, Bell Laboratory Scratch Adhesion Tester, and the Ultra-Centrifugal Force Device. The subcommittee is continuing its work on adhesion, hardness, viscosity measurements, and water vapor permeability.

Subcommittee XXV on Cellulosic Coatings and Related Materials (N. C. Schultze, chairman) recommended the proposed Tentative Methods of Test for Alcohol in Methyl Isobutyl Ketone, for Permanganate Time of Lacquer Solvents and Diluents, and for Water in Lacquer Solvents and Diluents. The subcommittee also recommended the revisions of Tentative Specifications for Methyl Isobutyl Ketone (D 1153 - 51 T) and for Acetone (D 329 - 33). Adoption as standard is recommended of the Method of Test for Residual Odor of Lacquer Solvents and Diluents (D 1296 - 53 T). Collaborative work is progressing on exploratory investigation of moisture checking of furniture lacquers and on distensibility tests for predicting check resistance of wood lacquers. Work is also continuing on the development of a perspiration resistance test for lacquers.

Subcommittee XXIX on Painting of Metals (A. J. Eickhoff, chairman) has prepared drafts of a specification for the preparation of aluminum alloys for painting and of a method for preparation of magnesium alloy surfaces for painting.

This report has been submitted to letter ballot of the committee, which consists of 364 voting members; 152 members returned their ballots, of whom 136 have voted affirmatively and 0 negatively.

Respectfully submitted on behalf of the committee,

W. T. PEARCE,
Chairman.

W. A. GLOGER,
Secretary.

APPENDIX I

PROPOSED METHOD OF TEST FOR NONVOLATILE CONTENT OF HEAT-UNSTABLE RESIN SOLUTIONS BY USE OF FOIL[1,2]

This is a proposed method and is published as information only. Comments are solicited and should be addressed to the American Society for Testing Materials, 1916 Race St., Philadelphia 3, Pa.

Scope

1. This method of test for nonvolatile matter is applicable to solutions of heat-unstable resins in volatile organic solvents.

Outline of Method

2. A weighed sample of resin is spread under pressure between two weighed sheets of aluminum or tin foil. The coated foil sheets are separated, then dried for 2 hr at 105 C in a mechanical convection oven. The weight of the residue is determined and the nonvolatile content calculated.

Apparatus

3. (*a*) *Oven.*[3]—Mechanical convection type, maintained at 105 ± 2 C with both inlet and outlet vents open. For ovens with adjustable air flow rate, set the control damper at 50 per cent.

(*b*) *Aluminum or Tin Foil.*[4]—0.0015 to 0.0020 in. in thickness. Either one piece 6 by 12 in., cut from a roll, or two 6 by 6-in. pieces may be used. The foil must be perfectly smooth; if wrinkled, roll smooth as described in Section 4.

(*c*) *Plate Glass.*—Two pieces, $\frac{3}{16}$ in. thick; one piece $5\frac{1}{2}$ by $5\frac{1}{2}$ in. and one piece 7 by 7 in.

(*d*) *Device for Weighing Samples.*—For samples of moderate viscosity, use a 2- or 5-ml Luer syringe, a 15- or 30-ml vial dropping bottle, or a 10-ml Smith weight buret. For samples of high viscosity, use either a Luer syringe or dropping bottle after enlarging the disperser tip.

(*e*) *Roller, for Smoothing Foil.*—Use a polished and ground cylinder, preferably stainless steel, approximately 7 in. long and 2 in. in diameter.

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[1] This proposed method of test is under the jurisdiction of the ASTM Committee D-1 on Paint, Varnish, Lacquer, and Related Products. Publication as information requires letter ballot of the appopriate subcommittee of Committee D-1, and approval of the chairman and secretary of Committee D-1. Letter ballot of Committee D-1 as a whole is not required.

[2] Published as information June, 1955.

[3] In the development of this method, the following types of mechanical convection ovens were used: Forced Draft Isotemp Oven (Catalog No. 13-245-5A), Fisher Scientific Co., 717 Forbes St., Pittsburgh, Pa.; Mechanical Convection Ovens (Catalog Nos. 31079 and 1050), Precision Scientific Co., 3737 W. Cortland St., Chicago, Ill.; and Mechanical Convection Oven (Freas, Model No. 821), and Forced Convection Oven, 3300 w, 230 v, American Instrument Co., 8010 Georgia Ave., Silver Spring, Md. Other types may also be satisfactory.

[4] Aluminum foil, 50-ft roll, Arthur H. Thomas Co., 230 S. Seventh St., Philadelphia, Pa., as Catalog No. 1068; or E. H. Sargent and Co., 4647 W. Foster Ave., Chicago, Ill., as Catalog No. S-610-13, has been found satisfactory. Tin foil, in 6-in. squares, J. T. Baker Co., North Phillipsburg, N. J.; or Fisher Scientific Co., 717 Forbes St., Pittsburgh, Pa., has been found satisfactory.

(*f*) *Weight, for pressing sample.*[5]

(*g*) *Foil Holder.*—Two or more trays made of No. 22 gage aluminum as shown in Fig. 1. For the 6 by 6-in. foil, use a holder made from 6½ by 6½-in. trays.

Procedure

4. (*a*) The following directions are applicable when using the 6 by 12-in. foil sheets and the 12 by 6½-in. trays. Alternatively, two 6 by 6-in. foil sheets may be used in a similar manner with the 6½ by 6½-in. trays. In handling the foil, avoid wrinkling or creasing the sheets until after the sample has been dried. They may be rolled for convenience, but must be kept smooth throughout the weighing, pressing, and drying operations.

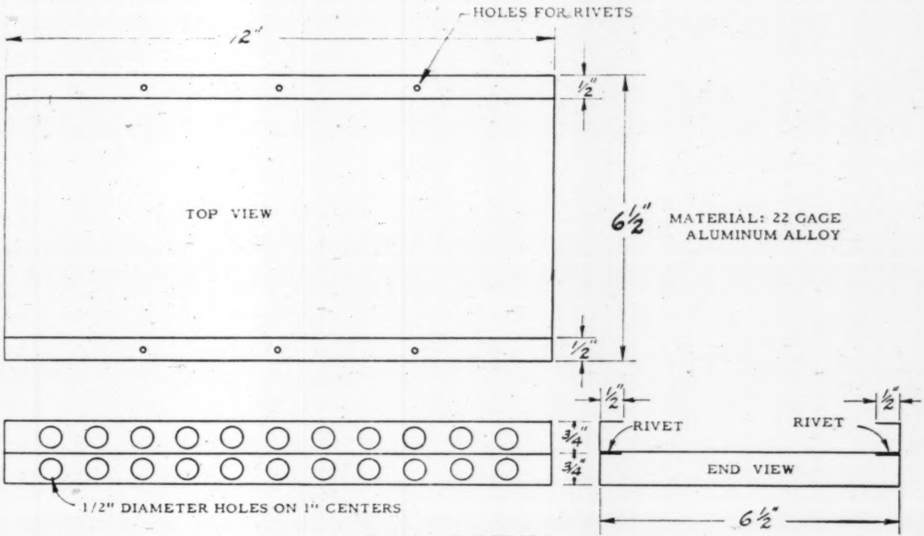
HOLES FOR RIVETS
12"
½"
TOP VIEW
6½"
MATERIAL: 22 GAGE ALUMINUM ALLOY
½"
½"
½"
¾"
¾"
RIVET
RIVET
END VIEW
6½"
1/2" DIAMETER HOLES ON 1" CENTERS

FIG. 1.—Foil Holder.

(*b*) Weigh the foil to the nearest 0.0001 g. Open and place half the foil on the 7 by 7-in. glass plate with the shiny side up. If necessary, roll smooth with the metal roller. Weigh by difference from the sample weighing device 0.9 to 1.1 g of sample to the nearest 0.0001 g, placing it on the center of that area of the foil covering the glass plate. Place the other half of the foil on top. Press the foil with the fingers by stroking outwards from the center to form a film which extends over a 2- to 3-in. diameter area in the center of the foil. Cover the foil with the second glass plate, centering the latter on the foil, and place the 20-lb weight on the plate for about 30 sec to cause the sample to spread uniformly into a thin film. In case a resin sample of low viscosity should extend beyond the edge of the foil, repeat the procedure but allow for a portion of the solvent to evaporate for a few minutes before covering and pressing the sample.

(*c*) After pressing, open the foil to its full length and place it in the foil holder. Place the latter in a mechanical convection oven at 105 ± 2 C for 2 hr. If a 6½ by 6½-in. tray is used, keep its open ends perpendicular to the air flow.

(*d*) Remove the holder from the oven and then remove the foil sheets from the holder. Return the dried film surfaces to the face to face position. While the foil is still warm, fold the edges together to enclose completely the dried film. Without undue delay, weigh to the nearest 0.0001 g.

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[5] Iron avoirdupois 20-lb, weight, with handle, Ohaus Scale Co., 1050 Commerce Ave., Union, N. J., or equivalent has been found satisfactory.

Calculation

5. Calculate the nonvolatile content, in per cent, as follows:

$$\text{Nonvolatile Content, per cent} = \frac{\text{wt of residue} \times 100}{\text{wt of sample}}$$

APPENDIX II

PROPOSED METHODS FOR ANALYSIS OF POLYVINYL BUTYRAL[1, 2]

These are proposed methods and are published as information only. Comments are solicited and should be addressed to the American Society for Testing Materials, 1916 Race St., Philadelphia 3, Pa.

Scope

1. (*a*) These methods cover procedures for the determination of polyvinyl alcohol, polyvinyl acetate, and total butyraldehyde in polyvinyl butyral.

(*b*) The procedures appear in the following order:

	Sections
Polyvinyl alcohol	3 to 6
Polyvinyl acetate	7 to 10
Butyraldehyde	11 to 15

Purity of Reagents

2. (*a*) Reagent grade chemicals shall be used in all tests. Unless otherwise indicated, it is intended that all reagents shall conform to the specifications of the Committee on Analytical Reagents of the American Chemical Society, where such specifications are available.[3] Other grades may be used, provided it is first ascertained that the reagent is of sufficiently high purity to permit its use without lessening the accuracy of the determination.

(*b*) References to water shall be understood to mean distilled water.

POLYVINYL ALCOHOL

Apparatus

3. *Flask*, 500-ml, with a ground-glass stopper.

Reagents

4. (*a*) *Ethylene Dichloride* (*technical grade*).

(*b*) *Phenolphthalein Indicator Solution* (*10 g per liter*).—Dissolve 1 g of phenolphthalein in 100 ml of ethanol (95 per cent).

(*c*) *Standard Alcoholic Potassium Hydroxide Solution* (*0.5 N*).

(*d*) *Pyridine - Acetic Anhydride Reagent.*—Mix slowly 1000 ml of pyridine and 87 ml of acetic anhydride. Make only about a week's supply, and keep it in a brown bottle.

Procedure

5. (*a*) Transfer 2.2 g of the dry sample to a clean, dry, 500-ml glass-stoppered flask. Add 25.0 ml of pyridine - acetic anhydride reagent. Insert the stopper, and heat the the flask on a sand or steam bath below the boiling point for 5½ hr. Swirl gently until the sample is com-

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[1] These proposed methods are under the jurisdiction of ASTM Committee D-1 on Paint, Varnish, Lacquer, and Related Products. Publication as information requires letter ballot of the appropriate subcommittee of Committee D-1, and approval of the chairman and secretary of Committee D-1. Letter ballot of Committee D-1 as a whole is not required.

[2] Published as information, June, 1955.

[3] "Reagent Chemicals, A.C.S. Specifications," American Chemical Society, Washington, D. C. (1950). For suggestions on the testing of reagents not listed by the American Chemical Society, see "Reagent Chemicals and Standards," Third Edition, by Joseph Rosin, D. Van Nostrand Co., Inc., New York, N. Y. (1955); "AnalaR Standards for Laboratory Chemicals," Fourth Edition, The British Drug Houses, Ltd., and Hopkin and Williams, Ltd., London (1949); and the "United States Pharmacopoeia," Fourteenth Revision, pp. 801–931 (1950).

pletely dissolved. Vent the flask occasionally during the first part of the heating period to prevent the stopper from blowing out.

(*b*) At the end of the 5½-hr period, add 25 ml of ethylene dichloride and shake well. Add 100 ml of water, and shake vigorously immediately after adding the water. Let the flask stand for ½ hr.

(*c*) Add a few drops of phenolphthalein solution and titrate with 0.5 *N* alcoholic KOH solution. Shake vigorously during the titration.

(*d*) *Blank.*—Run a blank determination on the reagents, following the same procedure as for the sample.

Calculation

6. Calculate the percentage of polyvinyl alcohol as follows:

$$\text{Polyvinyl alcohol, per cent} = \frac{(A - B)N \times 4.4}{C}$$

where:

A = milliliters of KOH solution required for titration of the blank,
B = milliliters of KOH solution required for titration of the sample,
N = normality of the KOH solution, and
C = grams of sample used.

POLYVINYL ACETATE

Apparatus

7. *Wide-Mouth Flask*, 500-ml capacity, equipped with a metal reflux condenser.

Reagents

8. (*a*) *Standard Alcoholic Hydrochloric Acid Solution* (*0.5 N*).

(*b*) *Methanol.*

(*c*) *Phenolphthalein Solution* (*10 g per liter*).—See Section 4(*b*).

(*d*) *Alcoholic Potassium Hydroxide Solution* (*28 g KOH per liter*).—Dissolve 33 g of potassium hydroxide (85 per cent KOH) in ethyl alcohol and dilute to 1 liter with methanol. This solution is approximately 0.5 *N*.

Procedure

9. (*a*) Transfer 2.15 g of the dry sample to the 500-ml flask. Add 200 ml of methanol, measured in a graduate. Measure from a buret 25.0 ml of KOH solution (28 g KOH per liter). Reflux on a sand or water bath for 2 hr. Rinse down the condenser and flask with a small amount of water, add a few drops of phenolphthalein, and back-titrate, using 0.5 *N* alcoholic HCl.

(*b*) *Blank.*—Run a blank determination on the reagents, following the same procedure as for the sample.

Calculation

10. Calculate the percentage of polyvinyl acetate as follows:

$$\text{Polyvinyl acetate, per cent} = \frac{(A - B)N \times 8.6}{C}$$

where:

A = milliliters of HCl required for back-titration of the blank,
B = milliliters of HCl required for back-titration of the sample,
N = normality of the HCl, and
C = grams of sample used.

TOTAL BUTYRALDEHYDE

Apparatus

11. (*a*) *Erlenmeyer Flask*, 500-ml capacity, with a standard-taper ground-glass joint.

(*b*) *Glass Reflux Condenser*, 12-in., having a standard-taper ground-glass joint for fitting to the flask.

Reagents

12. (*a*) *Bromphenol Blue Indicator Solution*

(*b*) *n-Butanol.*

NOTE 1.—The same lot of *n*-butanol should be used for all determinations that are to be compared.

(*c*) *Hydroxylamine Hydrochloride Solution (0.5 N).*

(*d*) *Methanol.*

(*e*) *Standard Sodium Hydroxide Solution (0.5 N).*

Blank Determination

13. (*a*) Place 50 ml of *n*-butanol and 50 ml of the hydroxylamine hydrochloride solution in the 500-ml Erlenmeyer flask, and fit by means of the ground-glass joint to the 12-in. reflux condenser. Be sure the ground-glass joint is dry. Add a porous plate boiling chip, and reflux for 2 hr on a hot plate. Cool to 24 ± 2 C.

(*b*) Add exactly 5 drops of bromphenol blue indicator and 50 ml of methanol to the solution and titrate with 0.5 *N* NaOH to a green end point (Note 2). Run at least two blank determinations checking to within 0.5 ml of each other, titrating to the same end point at 24 ± 2 C (Note 3).

NOTE 2.—The pH value of the blank and sample vary with temperature; if the temperature is raised, the green end point will turn yellow and if the temperature is lowered the green end point will turn blue. The pH value of the blank changes more quickly than the pH of the sample solution for a given change in temperature. Therefore, the blank is titrated and kept at 24 ± 2 C and the sample is titrated at the same temperature.

NOTE 3.—The color change of the indicator will be a gradual one from yellow to green to blue. No sharp transition point will be found. Choose a point of yellow green to green coloration. A buffer solution containing 2.05 g of potassium acid phthalate, 24 ml of 0.1 *N* H_2SO_4, and 50 ml of methanol gives a color matching a blank titrated with 6.85 ml of 0.0938 *N* NaOH. The color in the buffer solution will fade out but the regular blank may be kept as a standard for the determination.

Procedure for Analysis of Sample

14. (*a*) Transfer 2 g of the dry sample, weighed to the nearest 0.1 mg, to the 500-ml Erlenmeyer flask. Add 50 ml of *n*-butanol and 50 ml of hydroxylamine hydrochloride solution, and attach the 12-in reflux condenser. Be sure the ground-glass joint is dry. Add a boiling chip, and reflux for 2 hr (Note 4).

(*b*) Cool, add 5 drops of bromphenol blue, and titrate with 0.5 *N* NaOH solution until at least two-thirds of the expected requirement has been run in. Add 50 ml of methanol. At the first appearance of a green tinge, bring the flask to 24 ± 2 C (Note 5). Titrate to the same color as the blank (Note 6).

NOTE 4.—The resin gradually forms a milky emulsion. At this point, the reaction tends to bump and must be watched. After approximately 1.5 hr, the bumping lessens considerably and the mixture clears.

NOTE 5.—The heat of neutralization changes the temperature during the titration.

NOTE 6.—The blank may be diluted to give the same intensity of color as in the analysis of the sample if the percentage of butyraldehyde in all determinations is fairly constant. Otherwise, adjust the intensity of color by the amount of indicator present.

Calculation

15. Calculate the percentage of total butyraldehyde as follows:

$$\text{Butyraldehyde, per cent} = \frac{(A - B)N \times 7.2}{C}$$

where:

A = milliliters of NaOH solution required for titration of the sample,

B = milliliters of NaOH solution required for titration of the blank,

N = normality of the NaOH solution, and

C = grams of sample used.

REPORT OF COMMITTEE D-2
ON
PETROLEUM PRODUCTS AND LUBRICANTS*

The following recommendations of the subordinate groups of Committee D-2 on Petroleum Products and Lubricants have been approved by Committee D-2, in accordance with the regulations of the Society, and are presented herewith.

PROPOSED METHODS TO BE PUBLISHED AS INFORMATION

It is recommended that the following 12 proposed methods be published as information only as appended to this report:[1]

Appendix I. Test for Emulsion Stability of Soluble Cutting Oils.
Appendix II. Test for Galvanic Corrosion Associated with Instrument Lubricating Oils.
Appendix III. Test for Blocking Point of Paraffin Wax.
Appendix IV. Test for Oxidation Stability of Paraffin Wax (Peroxide Method).
Appendix V. Test for Vanadium in Residual Fuel Oil.
Appendix VI. Test for Estimation of Heat of Combustion of Liquid Petroleum Products.
Appendix VII. Test for Tetraethyllead in Gasoline by Direct-Reading Polarograph.
Appendix VIII. Test for Consistency of Semifluid Lubricating Greases.
Appendix IX. Test for Estimation of Deleterious Particles in Lubricating Grease.
Appendix X. Test for Benzene, Toluene, Ethylbenzene, and Individual Xylenes by Infrared Spectrophotometry.
Appendix XI. Test for Measuring the Color of Petroleum Products (ASTM Color Scale).
Appendix XII. Test for Water in Bituminous Materials.

NEW TENTATIVES

Committee D-2 recommends that the following two methods of test be accepted for publication as tentative, as appended hereto:[2]

Tentative Method of Test for:

Lubricating Qualities of Graphites, and
Trace Concentrations of Tetraethyllead in Primary Reference Fuels.

REVISIONS OF TENTATIVES

Committee D-2 recommends the revision of the following 15 tentatives, as indicated:

D 90 – 50 T,[3] Sulfur in Petroleum Products by the Lamp-Gravimetric Method:

Section 1, Scope.—Replace with the following:

1. (*a*) This method describes procedures for the determination of total sulfur in concentrations above 0.002 per cent by weight in liquid petroleum products.

NOTE 1.—Results obtained by this method, where applicable, are equivalent to those obtained by ASTM Method D 1266, Test for Sulfur in Petroleum Products and Liquified Petroleum Gases by the CO_2-O_2 Lamp Method, within the limits of precision and accuracy of the two methods.

(*b*) The direct burning procedure (Section 6) is applicable to such materials as gasoline, kerosine, naphtha, and other liquids that can be burned completely and without smoking in a wick lamp. The blending procedure (Section 7) is applicable to aromatics, gas oils and distillate fuel oils, naphthenic acids, alkyl phenols, and many other materials that cannot be burned satisfactorily by the direct burning procedure.

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* **Presented at the Fifty-eighth Annual Meeting of the Society, June 26–July 1, 1955.**

[1] These methods appear in the 1955 Compilation of ASTM Standards on Petroleum Products and Lubricants.

[2] The new tentatives appear in the 1955 Book of ASTM Standards, Part 5.

[3] **1952 Book of ASTM Standards, Part 5.**

(*c*) Halogens, nitrogen, phosphorus or other acid-forming elements do not interfere in the analysis of commercial gasolines. Elemental sulfur is not quantitatively determined by this procedure.

D 94 - 52 T,[3] Test for Saponification Number of Petroleum Products by Color-Indicator Titration:

Section 8.—Add the reference "(Note 6)" after sentence two, renumbering subsequent references accordingly.

Note 6.—Add a new Note 6 to precede the present Note 6, renumbering subsequent notes accordingly, to read as follows:

Note 6.—Where saponification numbers below 1 are expected, better precision may be obtained by substituting 0.1 *N* KOH and HCl for the 0.5 *N* reagents in Sections 5, 6, and 8.

D 130 - 54 T,[4] Test for Copper Corrosion by Petroleum Products (Copper Strip Test):

Figure 1.—Replace by the accompanying Fig. 1.

Footnote 2.—Add a new Footnote 2, renumbering subsequent footnotes accordingly, to read as follows:

[2] The corresponding method of the Institute of Petroleum (London) is Method No. 154.

Section 4(d).—Revise to read as follows:

(*d*) *Copper Corrosion Standards,*[7] consisting of reproductions of typical strips representing increasing degrees of tarnish and corrosion as listed under "Description" in Table I. These reproductions are lithographically printed on an aluminum sheet and are encased in plastic for protection. Keep covered when not in use to avoid fading (Note 2) due to light.

Note 2.—Revise to read as follows:

Note 2.—Evidence of fading can be detected by comparing two different sets, one of which has preferably been carefully protected from light; the one which shows evidence of fading should be replaced. Alternately, a ½ in. opaque strip may be placed across the top of the colored strips and removed at intervals to inspect for fading.

Footnote 7.—Add a new Footnote 7 to read as follows:

[7] The ASTM Copper Strip Corrosion Standards approved by Committee D-2 are available on order from ASTM Headquarters, 1916 Race St., Philadelphia 3, Pa. The cost is $25 per set; 15 per cent discount for orders of 10 or more; there is an additional charge for overseas mailing.

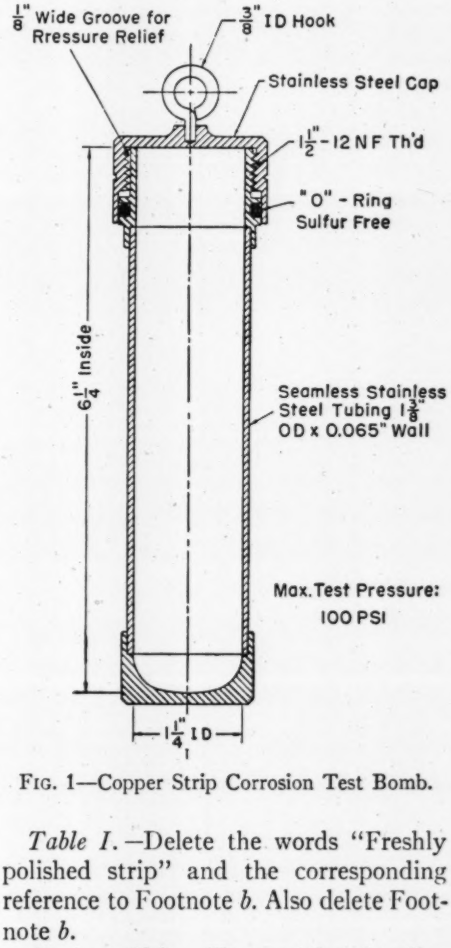
1/8" Wide Groove for Rressure Relief
3/8" ID Hook
Stainless Steel Cap
1 1/2"-12 NF Th'd
"O" - Ring Sulfur Free
6 1/4" Inside
Seamless Stainless Steel Tubing 1 3/8" OD x 0.065" Wall
Max. Test Pressure: 100 PSI
1 1/4" ID

Fig. 1—Copper Strip Corrosion Test Bomb.

Table I.—Delete the words "Freshly polished strip" and the corresponding reference to Footnote *b*. Also delete Footnote *b*.

Section 6(a).—Change the heading and the first part of the first sentence to read: "6. (*a*) *Tests at 122 F and 212 F on Less Volatile Materials.*—Place 30 ml of sample, completely clear and free of any suspended or entrained water (Note 4), into a chemically clean, dry 25- by 150-mm test tube, and . . . ."

Section 6(b).—Change the heading and

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[4] **1954 Supplement to Book of ASTM Standards, Part 5.**

the first part of the first sentence to read: "(*b*) *Tests at 212 F for Aircraft Engine Fuels.*—Place 30 ml of sample, completely clear and free of any suspended or entrained water (Note 4), into a chemically clean, dry 25- by 150-mm test tube, and . . . ."

Section 6(c).—Delete the words:

Observe the strip before removal from the test tube or bottle to see whether the sample does or does not meet specifications. If the appearance of the strip before removal from the test tube is such as to indicate that more careful examination will be necessary.

Section 7.—Revise to read as follows:

7. *Interpretation.*—Interpret the corrosiveness of the sample accordingly as the appearance of the test strip agrees with one of the strips of the ASTM Copper Corrosion Standards (Paragraph 4(*d*)).

(*a*) The freshly polished strip is included in the set of Corrosion Standards only as an indication of appearance of a properly polished strip before a test run; it is not possible to duplicate this appearance after a test even with a completely noncorrosive sample.

(*b*) When a strip is in the obvious transition state between that indicated by any two adjacent Corrosion Standard Strips, judge the sample by the more tarnished Standard Strip.

(*c*) A claret red strip in the No. 2 Classification can be mistaken for a magenta overcast on brassy strip in the No. 3 Classification if the brassy underlay of the latter is completely masked by a magenta overtone. To distinguish, immerse the strip in acetone; the former will appear as a dark orange strip while the latter will not change.

(*d*) To distinguish multicolored strips in Classifications 2 and 3, place a test strip in a 20 by 150 mm test tube and bring to a temperature of 600 to 700 F in 4 to 6 min with the tube lying on a hot plate. Adjust to temperature by observing an ASTM high distillation thermometer in a second test tube. If the strip belongs in Classification 2, it will assume the color of a silvery and then a gold strip. If in Classification 3 it will take on the appearance of a transparent black, etc. as described in Classification 4.

(*e*) Repeat the test if blemishes due to finger prints are observed, or due to spots from any particles or water droplets that may have touched the test strip during the digestion period. Repeat the test also if the sharp edges along the flat faces of the strip appear to be in a classification higher than the greater portion of the strip; in this case it is likely that the edges were burnished excessively during polishing.

Section 8.—Add a new Section 8 to read as follows:

8. *Report.*—Report the corrosiveness in accordance with one of the four numbered classifications listed in Table I.

D 270 – 53 T,[5] Method of Sampling Petroleum and Petroleum Products:

Section 6(d).—Change to read as follows:

(*d*) *Package Lots* (*Cans, Drums, Barrels or Boxes*).—Take samples from a sufficient number of the individual packages to prepare a composite sample which will be representative of the entire lot or shipment. Select at random the individual packages to be sampled. The number of such random packages will depend upon several practical considerations such as:

(*1*) The tightness of the product specifications,

(*2*) The source and type of the material and whether or not more than one production batch may be represented in the lot, and

(*3*) Previous experience with similar shipments, particularly with respect to the uniformity of quality from package to package.

In most cases, the number specified in Table III (accompanying Table I) will be satisfactory.

Table III.—Replace Table III by the accompanying Table I.

Section 7.—Reletter as Section 7(*a*). Add new Paragraphs (*b*) and (*c*), as follows:

(*b*) When sampling volatile products, the sampling apparatus shall be filled and allowed to drain before drawing the sample. If the sample is to be transferred to another container, this container shall also be rinsed with some of the volatile product and then drained. When the actual sample is emptied into this container, the sampling apparatus should be up-ended into the opening of the sample container and remain in this position until the contents have been transferred so that no unsaturated air will be entrained in the transfer of the sample.

(*c*) When sampling other than volatile liquid products (2 lb Rvp or less), the sampling apparatus shall be filled and allowed to drain before drawing the actual sample. If the actual sample is to be transferred to another container,

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[5] **1953 Supplement to Book of ASTM Standards, Part 5.**

TABLE I.—MINIMUM NUMBER OF PACKAGES TO BE SELECTED FOR SAMPLING. (Table III, D 270)

No. of Packages in the Lot	No. of Packages to be Sampled	No. of Packages in the Lot	No. of Packages to be Sampled	No. of Packages in the Lot	No. of Packages to be Sampled
1 to 3	All	513 to 729	9	2 745 to 3 375	15
4 to 64	4	730 to 1 000	10	3 376 to 4 096	16
65 to 125	5	1 001 to 1 331	11	4 097 to 4 913	17
126 to 216	6	1 332 to 1 728	12	4 914 to 5 832	18
217 to 343	7	1 729 to 2 197	13	5 833 to 6 859	19
344 to 512	8	2 198 to 2 744	14	6 860 or over	20

TABLE II.—REPORTED BEHAVIOR OF HYDROCARBON COMPOUNDS BY THE COLOR INDICATOR AND ELECTROMETRIC BROMINE NUMBER METHODS. (Table II, D 1158)

Compound	Purity, per cent	Bromine Number				
		Theory	Color Indicator Method		Electrometric Method	
			Found	Deviation	Found	Deviation
BRANCHED CHAIN OLEFINS						
Propylene Trimer	[i]	126.6	154.7	+28.1	140[k]	+13.4
Propylene Tetramer	[j]	95	123.5	+28.5	112.8[l]	+17.8
Isobutene Trimer		95	96.3	+1.3	...	...
Isobutene Tetramer	[d]	71.2	71.9	+0.7	...	...

[i] For C_9 olefin concentrate, the boiling range according to the ASTM Method D 86, Test for Distillation of Gasoline, Naphtha, Kerosine, and Similar Petroleum Products, 1954 Supplement to Book of ASTM Standards, Part 5, is 10 per cent at 258 F, 50 per cent at 273 F, 90 per cent at 282 F.

[j] For C_{12} olefin concentrate, the boiling range according to the ASTM Method D 86 is 10 per cent at 356 F, 50 per cent at 364 F, 90 per cent at 374 F.

[k] In absence of mercuric chloride, the bromine number found was 130.4.

[l] In absence of mercuric chloride, the bromine number found was 101.6.

the sample container shall be rinsed with some of the product to be sampled and drained before it is filled with the actual sample.

Section 45(b).—Change to read as follows:

(*b*) *Cooling Bath.*—A bath, Fig. 7, of sufficient size to hold the sample container and a cooling coil of about 25 ft of copper tubing ($\frac{3}{8}$ in. or less outside diameter) is required when using the procedure described in Paragraph (*g*). One end of the coil is provided with a connection for attaching it to the tank sampling tap or valve. The other end is fitted with a suitable valve (outlet) of good quality. A removable copper tube of $\frac{3}{8}$ in. or less outside diameter and of sufficient length to reach the bottom of the sample container is connected to the open end of the outlet valve.

D 439 - 54 T,[4, 6] Specifications for Gasoline:

Table I.—Under "Vapor Pressure, max, lb," column "S," change the values for gasoline from "9.5" to "10[j]," with a footnote reading: "These values shall be 9.5 in Arizona, California, Colorado, Nevada, New Mexico, and Utah."

D 447 - 52 T,[3] Test for Distillation of Plant Spray Oils:

Appendix: Section A1.—In the table under "Dimensions, cm" and "Permissible Variations, cm," change the numbers for "Length of vapor tube" from "17.50" and "±0.5" to "10" and "±0.3," respectively.

Appendix: Section A2.—In the fifth sentence change "0.259" to "0.26."

D 611 - 53 T,[5] Test for Aniline Point and Mixed Aniline Point of Petroleum Products and Hydrocarbon Solvents:

Revise as appended hereto.[7]

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[6] See Editorial Note, p. 460.

[7] The revised tentative appears in the 1955 Book of ASTM Standards, Part 5.

D 721 – 53 T,[5] Test for Oil Content of Petroleum Waxes:

Section 8(b).—Change the values of reproducibility for oil contents under 2 per cent from "0.2" to "0.25" per cent.

D 974 – 54 T,[4] Test for Neutralization Value (Acid and Base Numbers) by Color-Indicator Titration:

Section 3.—In the first sentence change "alpha-naphtholbenzein" to "*p*-naphtholbenzein."

Section 5(d).—Revise to read as follows:

(*d*) *p-Naphtholbenzein Indicator Solution.*—Prepare a solution containing 10 g of *p*-naphtholbenzein[5] per liter of titration solvent (Paragraph (*c*)). The solid *p*-naphtholbenzein shall contain less than 0.5 per cent chlorine and shall be in the form of a reddish-brown amorphous powder.

Footnote 5.—Replace this footnote with the following:

[5] Solid *p*-naphtholbenzein is available from Distillation Products Industries, Eastman Organic Chemicals Department, Rochester 3, N. Y.

Section 7(a).—In the second sentence change "3 ml" to "0.5 ml."

Section 7(c).—In the first sentence change "3 ml" to "0.5 ml."

Section 11.—Add the following Note:

NOTE 10.—The precision of this method is under study by Research Division VI on Analysis of Lubricants, of ASTM Committee D-2 on Petroleum Products and Lubricants.

D 1018 – 49 T,[3] Test for Hydrogen in Petroleum Fractions by the Lamp Method:

Section 6.—Revise to read as follows:

6. (*a*) *Repeatability.*—Duplicate results by the same operator should not be considered suspect unless they differ by more than the following amount:

Hydrogen Content, per cent by weight	Repeatability
11 to 16	0.11

(*b*) *Reproducibility.*—The results submitted by each of two laboratories should not be considered suspect unless they differ by more than the following amount:

Hydrogen Content, per cent by weight	Reproducibility
11 to 16	0.18

(*c*) *Accuracy.*—A result should not differ from the true value by more than the following amount:

Hydrogen Content, per cent by weight	Accuracy
11 to 16	0.11

D 1158 – 52 T,[3] Test for Bromine Number of Petroleum Distillates (Color-Indicator Method), and D 1159 – 52 T,[3] Test for Bromine Number of Petroleum Distillates (Electrometric Method):

Appendix: Table II.—After 3-Methyl-2-Isopropyl-1-Butene insert the compounds and the corresponding data as shown in the accompanying Table II.

D 1220 – 52 T,[8] Methods of Calibrating Liquid Containers:

Section 4(b).—Add as sentence seven the following:

If the tension determined for the working tape is not sufficient to hold the tape in the proper position, additional tension should be applied and a correction made to bring the reading into agreement with that obtained with the Master tape. The amount of correction shall not exceed more than 0.01 ft for each 100 ft of line in use.

Section 7.—Add a new Paragraph (*c*) to read:

(*c*) The calibration procedures outlined in Part I require that the interior upright cylindrical surface and roof supporting members, such as columns and braces of the tank, be clean and free of any foreign substances such as residue of commodities adhering to the sides such as rust, dirt, emulsion, paraffin, etc. Examination and inspection of a tank may indicate the need for thorough cleaning if the correct established capacity is to be assured.

Section 41.—Add a new Paragraph (*c*) to read:

(*c*) All newly prepared gage tables shall show thereon the date on which such table becomes effective. The basis for selecting such a date in the given case shall be dependent upon the individual circumstances and the needs of the parties concerned. However, it is intended that the effective date be established, taking into consideration circumstances of which the following are typical but not limiting:

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[8] Issued as separate reprint, January, 1954.

(*1*) Date the new tank is first used,

(*2*) Date the old tank is recalibrated, and

(*3*) Date agreed upon by contract for purchase, sale, or exchange.

Include a Procedure for Calibrating Liquid Containers (Spheroids).[9]

Include a Procedure for Calibrating Liquid Containers (Spheres).[9]

Include a Procedure for Calibrating Tank Car Tanks (Pressure and Non-Pressure Types).[9]

D 1266 – 53 T,[5] Test for Sulfur in Petroleum Products and Liquefied Petroleum Gases by the CO_2-O_2 Lamp Method:

Revise as appended hereto.[7]

Revisions include changes in scope, apparatus, procedure, calculations, and a new Section 6 on control of combustion.

D 1319 – 54 T,[4] Test for Hydrocarbon Types in Liquid Petroleum Products (Fluorescent Indicator Adsorption (FIA Method):

Section 1.—Change the last sentence to read: "Samples containing appreciable amounts of C_5 hydrocarbons should be depentanized to avoid errors which may be due to volatilization caused by heat of adsorption."

Section 5(g).—Change the first sentence to read:

(*g*) When the sample has advanced another 100 to 150 mm down the column, again mark the zones as described above, but in the reverse order, so as to minimize errors due to the advancement of boundary positions during readings.

REVISION OF STANDARD AND REVERSION TO TENTATIVE

Committee D-2 recommends that the Standard Method of Test for Olefinic Plus Aromatic Hydrocarbons in Petroleum Distillates (**D 1019 – 51**)[3] be revised as appended hereto and reverted to tentative status.[7]

STANDARD REVERTED TO TENTATIVE

Because of pending revisions now under consideration, Committee D-2 recommends that the Standard Method of Test for Dilution of Crankcase Oils (**D 322 – 35**)[3] be reverted to tentative status.

ADOPTION OF TENTATIVES AS STANDARDS WITHOUT REVISION

Committee D-2 has reviewed the following six tentatives which have stood two or more years without revision, and which represent best present-day practices, and recommends that they be approved for reference to letter ballot of the Society for adoption as standard without revision:

Test for Aromatic Hydrocarbons in Olefin-Free Gasolines by Silica Gel Adsorption (**D 936 – 51 T**),[3]

Test for Oxygen in Butadiene Vapors (Manganous Hydroxide Method) (**D 1021 – 53 T**),[5]

Test for Effect of Grease on Copper (**D 1261 – 53 T**),[5]

Test for Lead in New and Used Greases (**D 1262 – 53 T**),[5]

Method of Sampling Liquefied Petroleum Gases (**D 1265 – 53 T**),[5] (this method is under joint jurisdiction with ASTM Committee D-3 on Gaseous Fuels), and

Test for Unsaturated Light Hydrocarbons (Silver-Mercuric Nitrate Method) (**D 1268 – 53 T**).[5]

ADOPTION OF TENTATIVES AS STANDARDS WITH REVISIONS

Committee D-2 has reviewed the following three tentatives which have stood one or more years without revision, and which represent best present-day practices, and recommends that they be approved for reference to letter ballot of the Society for adoption as standard with the following revisions:

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[9] These procedures have been incorporated in the Methods for Calibrating Liquid Containers (ASTM Designation: D 1220), issued as a separate reprint.

D 1015 – 49 T,[3] Test for Measurement of Freezing Points for Evaluation of Purity:

Section 3.—Add a new Paragraph (*i*) to read as follows:

> (*i*) *Silica Gel Funnel*, as shown in Fig. 5, for filtering compounds through silica gel to remove water. To be used only when specified in ASTM Method D 1016.

New Fig. 5.—Use Fig. 5 in Method D 1016[8] and renumber present Figs. 5 to 9 as 6 to 10.

Section 4.—Add a new Paragraph (*c*) to read as follows:

> (*c*) *Silica Gel.*—For use in silica gel funnel.[9] If the gel has been exposed to the atmosphere because of punctured or loosely sealed containers, before use, dry the gel in a shallow vessel at 300 to 400 F for 3 hr, then transfer while hot to an airtight container.

New Footnote 9.—Add a new Footnote 9, renumbering subsequent footnotes and references accordingly, to read as follows:

> [9] A satisfactory gel of 28 to 200 mesh may be obtained from the Davison Chemical Co., Baltimore 3, Md. Specify grade 912.

Section 6(c).—Add the following after the second sentence:

> When specified in ASTM Method D 1016, the sample is filtered directly into a freezing tube (*O* in Fig. 1) through silica gel to remove water. A detailed drawing of a funnel used for this purpose is shown in Fig. 5. Each time a freezing or melting curve is determined after the sample is melted it is necessary to remove the sample from the freezing tube and refilter it through silica gel into a dry-freezing tube to remove water.

D 1016 – 54 T,[4] Test for Determination of Purity from Freezing Points:

Section 1.—At the end of the first sentence, add a new footnote reference "[3]." Renumber subsequent footnotes and references thereto accordingly. Add a new footnote to read:

> [3] Numerical constants in this method were taken from the most recently published data appearing in "Tables of Physical and Thermodynamic Constants of Hydrocarbons," prepared by Research Project 24 of the American Petroleum Institute.

Sections 3(c) and *4(c).*—Delete and renumber subsequent paragraphs accordingly.

Footnote 5.—Delete and renumber subsequent footnotes and references accordingly.

Section 18(b).—Delete the last two sentences and replace with the following sentence: "See Sections 4(*c*), 6(*c*), and Fig. 5 of ASTM Method D 1015."

Fig. 5.—Delete.

Section 23(b).—Delete the last two sentences and replace with the following sentence: "See Sections 4(*c*), 6(*c*), and Fig. 5 of ASTM Method D 1015."

D 1267 – 53 T,[5] Test for Vapor Pressure of Liquefied Petroleum Gases:

Section 1.—Delete the word "intended."

Section 2(a).—At the end of the paragraph add a sentence to read as follows:

> **Caution.**—If the apparatus and procedure of this method are used at higher than the specified test temperature, the apparatus may go hydrostatic, particularly for samples of high propylene content introduced into the apparatus at temperatures near or below their boiling points.

REVISION OF STANDARDS, IMMEDIATE ADOPTION

Committee D-2 recommends immediate adoption of revisions of nine standards as indicated below, and accordingly requests the necessary nine-tenths affirmative vote at the Annual Meeting so that these revisions may be referred to Society letter ballot:

D 287 – 54,[4] Test for API Gravity of Petroleum and Its Products (Hydrometer Method):

Section 5(d).—In the first sentence change "half-scale" to "scale."

TABLE III.—INTAKE AIR TEMPERATURES AND CORRECTIONS TO BE APPLIED TO MICROMETER SETTINGS IN TABLE V AND TO OBSERVED MICROMETER READINGS FOR VARIOUS BAROMETRIC PRESSURES.

(Table VI of D 908)

Barometric Pressure		0.0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	Barometric Pressure
	To Correct Micrometer Setting for the Prevailing Barometric Pressure Subtract the Following Micrometer Values from the Values in Table V:											
	To Correct the Observed Micrometer Setting for the Prevailnig Barometric Pressure Add the Following Micrometer Values to the Micrometer Reading:											
21.0	Micrometer Corrections	0.222	0.220	0.217	0.215	0.212	0.210	0.207	0.205	0.202	0.200	21.0
	Intake Air Temperatures	60	60	60	60	60	60	60	60	60	60	
22.0	Micrometer Corrections	0.197	0.195	0.192	0.190	0.187	0.185	0.182	0.180	0.177	0.175	22.0
	Intake Air Temperatures	60	60	60	60	60	60	60	60	60	60	
23.0	Micrometer Corrections	0.172	0.170	0.167	0.165	0.162	0.160	0.157	0.155	0.152	0.150	23.0
	Intake Air Temperatures	60	60	60	60	60	60	60	60	60	60	
24.0	Micrometer Corrections	0.147	0.145	0.142	0.140	0.137	0.135	0.132	0.130	0.127	0.125	24.0
	Intake Air Temperatures	60	60	60	60	60	60	60	60	60	60	
25.0	Micrometer Corrections	0.122	0.120	0.117	0.115	0.112	0.110	0.107	0.105	0.102	0.100	25.0
	Intake Air Temperatures	60	60	60	60	60	60	61	63	64	66	
26.0	Micrometer Corrections	0.097	0.095	0.092	0.090	0.087	0.085	0.082	0.080	0.077	0.075	26.0
	Intake Air Temperatures	67	69	70	72	73	75	76	78	79	81	
27.0	Micrometer Corrections	0.072	0.070	0.067	0.065	0.062	0.060	0.057	0.055	0.052	0.050	27.0
	Intake Air Temperatures	82	84	85	86	88	89	91	92	94	95	
28.0	Micrometer Corrections	0.047	0.045	0.042	0.040	0.037	0.035	0.032	0.030	0.027	0.025	28.0
	Intake Air Temperatures	97	98	100	101	103	104	106	107	109	110	
29.0	Micrometer Corrections	0.022	0.020	0.017	0.015	0.012	0.010	0.007	0.005	0.002	0.000	29.0
	Intake Air Temperatures	111	113	114	116	117	119	120	122	123	125	
	To Correct Micrometer Setting for the Prevailing Barometric Pressure Add the Following Micrometer Values to the Values in Table V:											
	To Correct the Observed Micrometer Setting for the Prevailing Barometric Pressure Subtract the Following Micrometer Values from the Micrometer Reading:											
30.0	Micrometer Corrections	0.003	0.005	0.008	0.010	0.013	0.015	0.018	0.020	0.023	0.025	30.0
	Intake Air Temperatures	126	127	129	130	132	133	135	136	138	139	

Section 7.—Under "Repeatability" change "0.1" to "0.2."

D 323 – 52,[3] Test for Vapor Pressure of Petroleum Products (Reid Method):

Section 1.—Change to read as follows:

1. This method is intended for the determination of the absolute vapor pressure (Note 6) of volatile, non-viscous petroleum products, except liquefied petroleum gas.

Note 6.—Change to read as follows:

NOTE 6.—Because the external atmospheric pressure is counteracted by the atmospheric pressure initially present in the air chamber, Reid vapor pressure is approximately the vapor pressure of the fuel at 100 F in pounds per square inch absolute.

D 525 – 49,[3] Test for Oxidation Stability of Gasoline (Induction Period Method):

Section 1.—At the end of the section add a sentence to read:

It should be recognized, however, that its correlation with the formation of gum in storage may vary markedly under different storage conditions and with different gasolines.

D 874 – 51,[3] Test for Sulfated Residue from New Lubricating Oils:

Section 1.—Replace with the following:

1. (*a*) This method describes a procedure for determining the sulfated residue from unused lubricating oils containing additives and from additive concentrates used in compounding. These additives usually contain one or more of the following metals: barium, calcium, magnesium, zinc, potassium, sodium, and tin. They may be in combination with sulfur, phosphorus, and/or chlorine.

(*b*) The sulfated residue may be used to indicate the concentration of known metal-containing additives in new oils. Barium, calcium, and magnesium are converted to their respective sulfates, and tin (stannic) to the oxide. Since zinc sulfate slowly decomposes to its oxide at the ignition temperature of the method, samples containing zinc may give variable results. (This variation may be minimized by prolonged ignition at 775 C to convert the zinc completely to its oxide.) Sulfur and chlorine do not interfere but phosphorus in concentrations above 0.1 per cent does interfere by remaining partially in the residue as the phosphate.

Note 1.—Revise to read as follows:

NOTE 1.—This method is not intended for the analysis of lubricating oils containing lead nor for used engine crankcase oils; for such samples use ASTM Method D 810, Test for Sulfated Residue, Lead, Iron, and Copper in New and Used Lubricating Oils; neither is it recommended for the analysis of non-additive lubricating oils; for such samples use ASTM Method D 482, Test for Ash Content of Petroleum Oils.

D 908 – 53,[5] Test for Knock Characteristics of Motor Fuel by the Research Method.

Table VI.—Replce Table VI with the accompanying Table III which includes a change in title.

Section 6(k).—Change to read as follows: "(*k*) **Intake Air Temperature,** measured at carburetor entrance with a mercury thermometer and maintained within ±2 F (±1.1 C) of the temperature specified for the prevailing barometric pressure in Table VI."

Section 8.—Add the following sentence after the first sentence: "The intake air temperature should be adjusted to correspond with the value specified for the prevailing barometric pressure as given in Table VI."

Section 10(b).—At the end of the paragraph add the following sentence: "An adjustment of the intake air temperature in accordance with Table VI may be required if a significant change in barometric pressure occurs during the day."

The following changes in the 1952 ASTM Manual of Engine Test Methods for Rating Fuels should also be made:

Page 82: Section 113(a).—Change the second paragraph to read: "**An air inlet thermometer** having a range of 60 to 160 F graduated in 1 F divisions is required for each method."

Page 133: Table XIII.—Change the

values for the "Intake Air Temperature, deg F" under the heading "Research Method" from "125 ± 2" to read "[d]."

Page 133: Table XIII.—Add a new footnote *d* to read as follows: "[d] Variable adjusted to correspond with value specified in Table VI for the prevailing barometric pressure."

Page 148: Section 316(c).—After the last sentence add the following sentence: "The intake air temperature used shall correspond with the value specified for the prevailing barometric pressure in Table VI."

Page 328: Section 624(a).—In the table change the thermometer range for the intake air of the Motor, Research, Aviation, and Cetane methods from "75 to 175" to read "60 to 160."

D 941 – 49,[3] Test for Density of Hydrocarbon Liquids by the Pycnometer:

Title.—Change to read "Density and Specific Gravity of Hydrocarbon Liquids by the Lipkin Bicapillary Pycnometer."

Section 1.—Add a Paragraph (*c*) to read as follows:

(*c*) This method provides a calculation procedure for converting density to specific gravity.

Section 2.—Reletter as Paragraph (*a*) and add Paragraph (*b*) as follows:

(*b*) *Specific Gravity* is the ratio of the mass (weight in vacuo) of a given volume of material at a temperature, t_1, to the mass of an equal volume of water at a reference temperature, t_2; or it is the ratio of the density of the material at t_1 to the density of water at t_2.

Section 3.—Change sentence three to read: "The density or specific gravity of the sample . . . ."

Section 7(e).—Change the first sentence to read: "(*e*) Place the pycnometer in the holder in a constant temperature bath adjusted to the test temperature (20 or 25 C) within ±0.02 C."

Section 9.—Change the title to read "Calculation."

Section 9(a).—Change to read as follows:

9. (*a*) Calculate the density of the sample as follows:

$$\text{Density, grams per milliliter at the test temperature (20 or 25 C)} = \frac{W}{V} + C$$

where:

W = weight in grams in air of sample contained in the pycnometer at the test temperature (20 or 25 C),

V = apparent volume in milliliters corresponding to the sum of the scale readings on the two arms of the pycnometer, as obtained from the calibration curve, and

C = air buoyancy correction, as obtained from Table I.

Section 9(b).—Replace with:

(*b*) Calculate the specific gravity of the sample at $\frac{t_1}{t_2}$ by dividing the density as calculated in Paragraph (*a*) by the relative density of water at the reference temperature (usually 15.56 C) as obtained from Table II. Specific gravity at t_1/15.56 C (t_1/60 F where t_1 is expressed in degrees F) can be changed to the conventional 15.56/15.56 C (60/60 F) by use of Table 23 in Standard D 1250, ASTM-IP Petroleum Measurement Tables.[5]

New Table.—Add a new Table II to be identical with Table I of ASTM Method D 1217, Test for Density and Specific Gravity of Liquids By Bingham Pycnometer.[3]

New Section.—Add a new Section 10, renumbering subsequent section accordingly, to read as follows:

10. *Report.*—In reporting density, give the test temperature and the units (For example: Density at 20 C = x.xxxx g per ml). In reporting specific gravity, give both the test temperature and the reference temperature, but no units (For example: Specific gravity, 15.56/15.56 C = x.xxxx). Carry out all calculations to five figures, and round off the final result to four figures.

D 1092 – 51,[3] Test for Apparent Viscosity of Lubricating Greases:

Section 1.—Revise to read as follows:

1. This method of test describes a procedure for measuring, in poises, the apparent viscosity of lubricating grease at room temperature (Note 1). Measurements are limited to the range of 25 to 60,000 poises at 10 reciprocal seconds and 1 to 100 poises at 15,000 reciprocal seconds. The results may be related to the ease of handling and dispensing and to starting and running torques of grease lubricated mechanisms.

New Section.—Add a new Section 9 to read as follows:

9. *Precision.*[6]—The following data (Note 7) should be used for judging the acceptability of results (95 per cent probability) according to the concept of precision as given in the Proposed Recommended Practice for Applying Precision Data Given in ASTM Methods of Test for Petroleum Products and Lubricants.

(*a*) Duplicate results by the same operator should be considered suspect if they differ by more than the following amounts:

Sample	Repeatability, per cent of mean					
	Shear Rate					
	30	100	300	1 000	3 000	10 000
Smooth NLGI No. 2 (SAE-20 Oil)..	18	6	6	6	11	7
Fibrous NLGI No. 2 (SAE-20 Oil)..	11	7	5	10	9	9

(*b*) The results submitted by each of two laboratories should not be considered suspect unless they differ by more than the following amounts:

Sample	Reproducibility, per cent of mean					
	Shear Rate					
	30	100	300	1 000	3 000	10 000
Smooth NLGI No. 2 (SAE-20 Oil)..	24	13	10	18	32	33
Fibrous NLGI No. 2 (SAE-20 Oil)..	33	27	19	19	32	25

New Note.—Add a new Note 6 to read as follows:

NOTE 6.—Precision data are not available for all types of grease but it is believed that the values given are approximately correct for other types. Furthermore, the technique of any laboratory may be checked by testing samples of the variety described.

New Note.—Add a new Note 7 to read as follows:

NOTE 7.—These data are based upon curve values of apparent viscosity at the six shear rates. A separate curve was drawn for each run.

D 1250 – 53,[5] ASTM-IP Petroleum Measurement Tables:

Provide an extension to Table 6, volume correction table with entry in API gravity, to cover the temperature range of 0 to −50 F, and an abridgement of this extension for Table 7, abridged volume correction table with entry in API gravity.

Replace Table 32 with a new abridged table for liquefied petroleum gases, to be designated Table 34.

These recommendations are not to be put into effect until the concurrence of the Institute of Petroleum is obtained.

D 1298 – 54,[4] Test for Specific Gravity of Petroleum and Its Products (Hydrometer Method):

Section 7.—Under "Repeatability," change "0.0003" to "0.0015"; under "Reproducibility," change "0.0005" to "0.0040."

Section 5(d).—In the first sentence change "half-scale" to "scale."

TENTATIVES CONTINUED WITHOUT REVISION

Committee D-2 has reviewed the following 22 tentatives which have stood for two or more years without revision, and recommends that they be continued as tentative without revision:

D 156 – 53 T, Saybolt Color of Refined Petroleum Products (Saybolt Chromometer Method),

D 217 – 52 T, Cone Penetration of Lubricating Grease,

D 396 - 48 T, Specifications for Fuel Oils,
D 445 - 53 T, Kinematic Viscosity,
D 483 - 52 T, Unsulfonated Residue of Petroleum Plant Spray Oils,
D 526 - 53 T, Tetraethyllead in Gasoline,
D 613 - 48 T, Ignition Quality of Diesel Fuels by the Cetane Method,
D 614 - 49 T, Knock Characteristics of Aviation Fuels by the Aviation Method,
D 855 - 52 T, Analysis of Oil-Soluble Sodium Petroleum Sulfonates,
D 875 - 53 T, Calculation for Olefins and Aromatics in Gasoline,
D 892 - 46 T, Foaming Characteristics of Crankcase Oils,
D 893 - 52 T, Normal Pentane and Benzene Insolubles in Used Lubricating Oils,
D 909 - 49 T, Knock Characteristics of Aviation Fuels by the Supercharge Method,
D 910 - 53 T, Specifications for Aviation Gasolines,
D 937 - 49 T, Penetration of Petrolatum,
D 972 - 51 T, Evaporation Loss of Lubricating Greases and Oils,
D 975 - 53 T, Classification of Diesel Fuel Oils,
D 976 - 48 T, Color of U. S. Military Gasoline, Automotive (Combat), by Means of an ASTM Color Standard,
D 1022 - 49 T, Peroxides in Butadiene by Ferrous-Titanous Method,
D 1216 - 52 T, Analysis of Calcium and Barium Petroleum Sulfonates,
D 1263 - 53 T, Leakage Tendencies of Automotive Wheel Bearing Greases, and
D 1264 - 53 T, Water Washout Characteristics of Lubricating Greases.

STANDARDS CONTINUED WITHOUT REVISION

Committee D-2 has reviewed the following 15 standards which have stood for six years or more without revision, and recommends that they be continued as standard without revision:

D 87 - 42, Melting Point of Paraffin Wax,
D 97 - 47, Cloud and Pour Points,
D 127 - 49, Melting Point of Petrolatum and Microcrystalline Wax,
D 128 - 47, Analysis of Grease,
D 187 - 49, Burning Quality of Kerosine,
D 219 - 36, Burning Quality of Long-Time Burning Oil for Railway Use,
D 239 - 30, Burning Quality of Mineral Seal Oil,
D 286 - 30, Autogenous Ignition Temperatures of Petroleum Products,
D 341 - 43, Standard Viscosity-Temperature Charts for Liquid Petroleum Products,
D 482 - 46, Ash Content of Petroleum Oils,
D 565 - 45, Carbonizable Substances in White Mineral Oil (Liquid Petrolatum),
D 566 - 42, Dropping Point of Lubricating Grease,
D 612 - 45, Carbonizable Substances in Paraffin Wax,
D 873 - 49, Oxidation Stability of Aviation Gasoline (Potential Gum Method), and
D 938 - 49, Congealing Point of Pharmaceutical Petrolatums.

AMERICAN STANDARDS

Committee D-2 recommends the following for action by ASA Sectional Committee Z11 on Petroleum Products and Lubricants:

Approval as American Standard:

Test for Rust-Preventing Characteristics of Steam-Turbine Oil in the Presence of Water (D 665 - 54),
Test for Aromatic Hydrocarbons in Olefin-Free Gasolines by Silica Gel Adsorption (D 936 - 51 T), if adopted as ASTM Standard,
Test for Oxidation Characteristics of Inhibited Steam-Turbine Oils (D 943 - 54),
Test for Measurement of Freezing Points for Evaluation of Purity (D 1015 - 49 T), if adopted as ASTM Standard,
Test for Determination of Purity from Freezing Points (D 1016 - 54 T), if adopted as ASTM Standard,
Test for Oxygen in Butadiene Vapors (Manganous Hydroxide Method) (D 1021 - 55),
Sampling Liquefied Petroleum Gases (D 1265 - 55), and
Test for Vapor Pressure of Liquefied Petroleum Gases (D 1267 - 55), as revised in this report.

Approval of Revised American Standards:

Test for Saponification Number of Petroleum Products by Color-Indicator Titration (D 94; Z11.20—1952), as revised in this report.
Test for API Gravity of Petroleum and Its Products, Hydrometer Method (D 287; Z11.31—1954), as revised in this report.
Test for Dilution of Crankcase Oils (D 322; Z11.29—1935), as reverted to tentative in this report.
Test for Vapor Pressure of Petroleum Products (Reid Method) (D 323; Z11.44—1952), as revised in this report.

- **Test for Distillation of Plant Spray Oils (D 447; Z11.43—1952), as revised in this report.**
- Test for Oxygen Stability of Gasoline (Induction Period Method) (D 525; Z11.63—1949), as revised in this report.
- Test for Oil Content of Petroleum Waxes (D 721; Z11.52—1953), as revised in this report.
- Test for Sulfated Residue from New Lubricating Oils (D 874; Z11.68—1951), as revised in this report.
- Test for Knock Characteristics of Motor Fuels by the Research Method (D 908; Z11.69—1953), as revised in this report.
- Test for Density of Hydrocarbon Liquids by the Pycnometer (D 941; Z11.62—1949), as revised in this report.
- Test for Olefinic Plus Aromatic Hydrocarbons in Petroleum Distillates (D 1019; Z11.71—1951), as revised in this report.
- Test for Apparent Viscosity of Lubricating Greases (D 1092; Z11.72—1951), as revised in this report.
- ASTM-IP Petroleum Measurement Tables (D 1250; Z11.83—1953), as revised in this report.
- Test for Specific Gravity of Petroleum and Its Products (Hydrometer Method) (D 1298; Z11.84—1954), as revised in this report.

The recommendations appearing in this report have been submitted to letter ballot of the committee, the results of which will be reported at the Annual Meeting.[10]

A report on "Sampling Diesel Locomotive Lubricating Oil for Spectrographic Analysis," prepared by Research Division III on Elemental Analysis, appears in the ASTM BULLETIN, September, 1955.

"Determination of the Shear Stability of Non-Newtonian Liquids," a report prepared by Neal D. Lawson, chairman, on behalf of Section B on Non-Newtonian Liquids of Research Division VII on Flow Properties, has been published as *STP No. 182.* The report indicates that any of the various procedures are capable of giving comparable results and that an ASTM test method for determining relative resistance of non-Newtonian liquids to permanent shear breakdown could therefore be written in general terms to permit the use of any type of equipment which could be operated to obtain the desired degree of breakdown with a reference liquid.

This report has been submitted to letter ballot of the committee, which consists of 116 voting members; 76 members returned their ballots, all of whom have voted affirmatively.

Respectfully submitted on behalf of the committee,

O. L. MAAG,
Chairman.

W. T. GUNN,
Secretary.

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[10] The letter ballot vote on these recommendations was favorable; the results of the vote are on record at ASTM Headquarters.

EDITORIAL NOTE

Subsequent to the Annual Meeting, Committee D-2 presented to the Society through the Administrative Committee on Standards the following recommendations:

Revision of Tentative Specification for:

Gasoline (D 439 – 54 T), and

Revision of Tentative Method of Test for:

Needle Penetration of Petroleum Waxes (D 1321 – 54 T).

These recommendations were accepted by the Standards Committee on September 15, 1955, and the revised tentatives appear in the 1955 Book of ASTM Standards, Part 5, and in the 1955 Compilation of ASTM Standards on Petroleum Products and Lubricants.

REPORT OF COMMITTEE D-3
ON
GASEOUS FUELS*

Committee D-3 on Gaseous Fuels and its seven subcommittees held a joint meeting in Pittsburgh, Pa., on May 27, 1954. Four of its subcommittees held individual meetings the same day. A fifth subcommittee meeting was held in Cincinnati, Ohio, on January 31, 1955.

RECOMMENDATIONS ACCEPTED BY THE ADMINISTRATIVE COMMITTEE ON STANDARDS

Subsequent to the 1954 Annual Meeting, Committee D-3 presented to the Society through the Administrative Committee on Standards the following recommendations:

New Tentative Method for:

Determination of Total Sulfur in Fuel Gases (**D 1072 - 54 T**).

Revision of Tentative Methods for:

Measurement of Gaseous Fuel Samples (**D 1071 - 49 T**).

These recommendations were accepted by the Standards Committee on September 28, 1954, and the new and revised methods appear in the 1954 Supplement to Book of ASTM Standards, Part 5.

ADOPTION OF TENTATIVES AS STANDARD WITHOUT REVISION

Committee D-3 recommends that the following tentative methods be approved for reference to letter ballot of the Society for adoption as standard without change:

Tentative Methods for Measurement of Gaseous Fuel Samples (**D 1071 - 54 T**),[1] and

Tentative Method of Sampling Liquefied Petroleum Gases (**D 1265 - 53 T**),[2] jointly with Committee D-2.

REVISION OF STANDARD, IMMEDIATE ADOPTION

Committee D-3 recommends for immediate adoption the following revisions of the Standard Method of Test for Calorific Value of Gaseous Fuels by the Water-Flow Calorimeter (**D 900 - 48**),[3] and accordingly asks for the necessary nine-tenths affirmative vote at the Annual Meeting in order that the revisions may be referred to letter ballot of the Society.

Section 1(*a*).—In the last sentence change the present values "300 to 3000" to read "475 to 3300" Btu per standard cubic foot. Add a Note as follows:

NOTE.—Determination of calorific value of the higher Btu gases within the maximum permissible differences requires careful observation by expert operators of procedures as specified in this method. See Section 20.

Section 4.—Add a new Paragraph (*h*), relettering the subsequent paragraphs accordingly, to read as follows:

(*h*) *Air Temperature Thermometer.*—A thermometer graduated in 0.5 F from 54 to 101 F shall be provided for measuring the temperature of the air in the vicinity of the calorimeter.

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* Presented at the Fifty-eighth Annual Meeting of the Society, June 26–July 1, 1955.

[1] 1954 Supplement to Book of ASTM Standards, Part 5.

[2] 1953 Supplement to Book of ASTM Standards, Part 5.

[3] 1952 Book of ASTM Standards, Part 5.

The scale error shall not exceed 0.3 F at any point.

Section 4(r).—Reletter as Paragraph (*s*) and revise to read as follows:

(*s*) *Water Tank.*—The water tank for tempering and equalizing the temperature of the water shall conform to the following requirements:

(*1*) *Equipment.*—Hot and cold water connections to a mixing manifold in which a thermometer can be inserted; air vent and overflow pipe near the top; water level gage; drain at the bottom; take-off connection at a point near the inlet weir of the calorimeter; suitable stirring device; filter if the tap water contains much sediment; cover to protect from dust and retard evaporation.

(*2*) *Materials of Construction.*—Tank, connecting pipe fittings, stirrer, etc., shall be of corrosion-resistant material such as copper or brass.

(*3*) *Capacity of Water Tank.*—Sufficient to contain an adequate amount of water for several calorific value tests, and the height shall not exceed the shortest horizontal dimension.

Section 5(b).—At the end of Item (*4*) add the following sentence: "The air-temperature thermometer (Section 4(*h*)) shall be mounted so that its bulb is within a few inches of the calorimeter surface and approximately at the mean height of the calorimeter body."

Section 5(c).—Following the words "cubic foot bottle" insert the following: "(or aspirator bottle)."

Section 6(e).—In the first sentence after the words "The psychrometer" add "and air-temperature."

Section 7.—Revise this entire section to read as follows:

7. *Calibration of Wet Test Meter.*—(*a*) The wet test meter shall be calibrated in accordance with procedures described in Sections 16 to 18, inclusive, or Section 19 of the Methods for Measurement of Gaseous Fuel Samples (ASTM Designation: D 1071).[1] For highest accuracy the procedure described in Section 19 should be followed, the rate of flow of the testing medium should be approximately the same as the rate of flow of gas when the meter is in use in a calorific value test. Air is preferable to gas as the testing medium. If the test of the meter shows a volume per revolution differing from 0.1000 cu ft, the appropriate calibration factor shall be used to calculate the volume of gas burned in a calorific value test.

(*b*) The meter should be calibrated in place at intervals not exceeding three months. Experience may show the need of more frequent calibrations.

Section 8(c).—Revise to read as follows, and add a new Note 2, renumbering the present Note 2 as 3:

(*c*) Adjust the gas meter temperature within ±1 F of the room temperature; level the meter with reference to the spirit levels mounted on the top by means of the adjusting screws in the feet; add water, if necessary, to raise the level in the meter somewhat above the pointer in the gage glass; pass a sufficient amount of gas through the meter to saturate the water with gas (Note 2); adjust the water level as described in Section 17(*e*) of Method D 1071.

NOTE 2.—The amount of gas required to saturate the water in the meter sufficiently for calorimetric purposes probably depends upon the composition of the gas. In the case of a 600 Btu carburetted water gas it has been found that 15 to 20 cu ft of gas must be passed through the meter at about 6 cu ft per hr to saturate the water. In the case of a 600 Btu mixture of carburetted water gas and natural gas about 10 cu ft of gas must be passed through the meter to saturate the water.

Section 8(f).—In the first sentence change "plus or minus 5 per cent" to read "±2 per cent."

Section 8(h).—Following Item (3) add a new Note 4, renumbering Note 3 as 5, and changing references accordingly, to read as follows:

NOTE 4.—Under extreme conditions of high temperature, low barometric pressure, and low relative humidity, it may be desirable to reduce permissible limits of excess air to 40 ± 2 per cent.

Section 10(b).—Revise the last sentence of Item (3) to read: "Determine the room temperature by reading the air-temperature thermometer mounted near the calorimeter as described in Section 4(*h*)."

Section 20.—Change the first sentence to read as follows: "For manufactured gases of about 540 Btu, natural gases of about 1050 Btu, and liquefied petroleum gases such as propane and butane of about 2400 to 3200 Btu, the maximum permissible difference between the results of duplicate determinations of total calorific value of a given sample of gas by the same observer using a single set of apparatus is 0.3 per cent." Add the following precautionary statement: "**Caution**—In order to obtain the indicated reproducibility, it is necessary to follow very carefully the procedures specified in this method. This statement applies particularly to gases of high calorific values, for example, those consisting largely of propane or butane or mixtures thereof."

Explanatory Note.—At the end of the text add the following explanatory note:

NOTE.—For summarized operating directions for water flow calorimeters see the Appendix.

Figure 8.—Delete all values for temperatures above 100 F.

Table I.—In Footnote *a* change "±5" to read "±2" per cent.

Tables II(a), IV, V, IX, X, XI, XII, and *XIII.*—Delete all values for temperatures above 100 F.

Appendix.—Following Table XIII add an appendix to read as follows:

APPENDIX

SUMMARIZED OPERATING DIRECTIONS WATER-FLOW CALORIMETERS

A1. The following summarized directions may be of use to those who are sufficiently familiar with the complete directions for this method and may desire only a reminder of the principal operations involved. It is not to be considered as a substitute for the detailed directions given in the text of the method, which should be followed in all cases. References to the detailed directions are given for each of the items below:

(*a*) *Adjustments for Humidity-Correction Procedure:*

(*1*) Fill water supply tank and adjust temperature of water (Section 8 (*a*)),

(*2*) Purge gas lines (Section 8 (*b*)),

(*3*) Adjust meter for temperature level, water level, and saturation of water with gas (Section 7),

(*4*) Test for gas leaks (Section 8 (*d*)),

(*5*) Start flow of water through system and expel air (Section 8 (*e*)),

(*6*) Light gas, adjust rate of gas flow, adjust primary air supply, and insert burner in calorimeter (Section 8 (*f*)),

(*7*) Adjust water flow to give proper temperature rise (Section 8 (*g*)), and

(*8*) Allow time for attainment of a steady thermal state and adjust damper (Section 8 (*h*)).

(*b*) *Adjustments for Humidity Control Procedure:*

(*1*) Make adjustments described in Items (*1*) to (*4*) of Paragraph (*a*),

(*2*) Start flow of water through calorimeter and through humidity controller (Section 9 (*b*)),

(*3*) Light gas, adjust rate of gas flow, adjust primary air supply, and open flue damper wide (Section 9 (*c*)),

(*4*) Attach special housing containing burner to calorimeter, then connect the humidity controller to the special burner housing (Section 9 (*d*)),

(*5*) Allow time for the attainment of a steady thermal state. Close flue damper until evidence of incomplete combustion is observed. Reduce gas flow to standard rate. Adjust humidity controller so as to maintain the proper value of *fh*. Adjust water flow in calorimeter to give the proper temperature rise (Section 9 (*e*)).

(*c*) *Procedure for Calorific Value Determination:*

(*1*) Prepare test record sheet, and make preliminary observations of barometric pressure and temperature, pressure and temperature of gas in meter, wet- and dry-bulb thermometer readings, temperature of flue gases, and time of one revolution of meter (Section 10 (*a*) and (*b*)),

(*2*) Start collection of condensate and record meter reading (Section 10 (*c*), Item (*1*)),

(*3*) Take first series of observations as follows: Make preliminary notation of water temperatures; shift water; make supplemental series of water temperatures; and weigh water (Section 10 (*c*), Items (*2*) to (*6*)),

(*4*) Take second and third series of observations (Section 10 (*d*)),

(*5*) Stop Collection of condensate and record meter reading and amount of condensate (Section 10 (*e*)),

(*6*) Repeat preliminary observations of Item (*1*) above (Section 10 (*f*)), and

(*7*) Turn off gas and then turn off water (Section 10 (*g*)).

The recommendations in this report have been submitted to letter ballot of the committee, the results of which will be reported at the Annual Meeting.[4]

ACTIVITIES OF SUBCOMMITTEES

Subcommittee II on Measurement of Gaseous Samples (H. S. Bean, chairman).—The revision of Tentative Methods for Measurement of Gaseous Fuel Samples (D 1071), accepted during the year by the Administrative Committee on Standards, was prepared by this subcommittee. It was recommended that the revised methods be adopted as standard.

Subcommittee III on Determination of Calorific Value of Gaseous Fuels (R. S. Jessup, chairman).—Early in 1955, this subcommittee gave consideration to proposed revisions of the Standard Method of Test for Calorific Value of Gaseous Fuels by the Water-Flow Calorimeter (D 900 - 48). The revisions as agreed upon by the subcommittee at its meeting on January 31, 1955, are referred to earlier in the report for immediate adoption. The principal feature of the revision relates to covering by cross-reference details of wet test meter calibration.

Subcommittee V on Determination of Special Constituents of Gaseous Fuels (L. T. Bissey, chairman) prepared the Tentative Method for Determination of Total Sulfur in Fuel Gases (D 1072 - 54 T) which was accepted during the year by the Administrative Committee on Standards.

Preliminary studies are under way on: (1) application of the Lusby platinum spiral method of sulfur determination to various fuel gases; and (2) determination of particulates in fuel gases.

Subcommittee VI on Determination of Water Vapor Content of Gaseous Fuels (S. W. Burdick, chairman).—The subcommittee plans to continue further experimental work on the Brickell method for determination of water vapor in fuel gases. Results of an extensive series of tests comparing this method with the dew point method have been distributed to all members for review and comment.

Subcommittee VII on Complete Analysis of Chemical Composition of Gaseous Fuels (D. V. Kniebes, chairman).—The former chairman, M. J. Stross, was obliged to resign in May, 1954, due to his assignment to other duties by his company. D. V. Kniebes was appointed to succeed Mr. Stross.

Comments had been requested from Committee E-14 on Mass Spectrometry regarding revision of the two mass spectrometer methods (D 1137 - 53 and D 1302 - 53 T) prepared by this subcommittee. A review of material supplied by Committee E-14 indicated the desirability of revising these methods to omit reference to specific instruments but to define a suitable mass spectrometer according to its ability to analyze a sample with the required accuracy. It is planned to proceed with revisions of Method D 1137 along these lines. Some more extensive changes in Method D 1302 will then be considered.

This report has been submitted to letter ballot of the committee, which consists of 36 members; 32 members returned their ballots, all of whom have voted affirmatively.

Respectfully submitted on behalf of the committee,

L. T. BISSEY,
Chairman.

K. R. KNAPP,
Secretary.

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[4] The letter ballot vote on these recommendations was favorable; the results of the vote are on record at ASTM Headquarters.

REPORT OF COMMITTEE D-4

ON

ROAD AND PAVING MATERIALS*

Committee D-4 on Road and Paving Materials held two meetings during the past year: in Chicago, Ill., on June 15, 1954, and in Cincinnati, Ohio, on February 4, 1955.

In the period since the last annual report, Committee D-4 has lost four members by death; namely, J. J. Paine, Shreve Clark, A. H. Bunte, and H. H. Miller. In recognition of their valuable contributions to the work of Committee D-4 and the loss which members of Committee D-4 feel in their passing, appropriate memorial resolutions were adopted by the committee and are being entered on the permanent records of Committee D-4 and of the Society.

At its meeting on February 4, 1955, B. A. Anderton was elected an Honorary Member of Committee D-4 in recognition of his long and meritorious service to the committee. Mr. Anderton served as secretary of Committee D-4 from 1946 to 1954. A. T. Goldbeck was elected an Honorary Member of Committee D-4 at its meeting on June 15, 1954, in recognition of his outstanding accomplishments in committee activities and his long service as an officer of Committee D-4.

NEW TENTATIVES

Committee D-4 recommends that the Recommended Practice for Quantities of Materials for Bituminous Surface Treatments be accepted for publication as tentative, as appended hereto.[1]

REVISION OF TENTATIVES

Committee D-4 recommends the revision of the following and their continuation as tentative:

Tentative Method of Test for Compressive Strength of Bituminous Mixtures (D 1074 - 52 T):[2]

Section 5 (b).—In line 6, change "4 hr." to read "5 hr."

Tentative Specifications for Crushed Stone, Crushed Slag, and Gravel for Single, Double or Multiple Bituminous Surface Treatments (D 1139 - 52 T):[2]

Revise as appended hereto.[3]

TENTATIVE REVISIONS OF STANDARDS

Specification for Mineral Filler for Sheet Asphalt and Bituminous Concrete Pavements (D 242 - 39):[2]

This specification is referenced in Specifications D 947 - 54 T and D 978 - 54 and the grading requirements in neither of these specifications contain a control on the No. 80 sieve whereas they do contain controls on the No. 100 sieve. It is therefore recommended that the following revision in Specifications D 242 - 39 be published as tentative.

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* Presented at the Fifty-eighth Annual Meeting of the Society, June 26–July 1, 1955.

[1] The new tentative appears in the 1955 Book of ASTM Standards, Part 3.

[2] 1952 Book of ASTM Standards, Part 3.

[3] The revised tentative appears in the 1955 Book of ASTM Standards, Part 3.

Section 3.—Change the present provision for not less than 95 per cent passing the No. 80 (177 micron) sieve to not less than 90 per cent passing the No. 100 (149 micron) sieve.

Method of Test for Distillation of Tars and Tar Products (D 20 – 52):[2]

Committee D-4 recommends that a new section on "Precision" be added to this method as follows:

Precision

The following data should be used for judging the acceptability of results (95 per cent probability):[a]

(a) Duplicate results by the same operator should be considered suspect if they differ by more than the following amount:

Repeatability..........1.1 per cent

(b) Results submitted by each of two laboratories should not be considered suspect unless they differ by more than the following amount:

Reproducibility.......2.3 per cent

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[a] See Proposed Recommended Practices for Applying Precision Data Given in ASTM Methods of Test for Petroleum Products and Lubricants, 1954 Compilation of ASTM Standards on Petroleum Products and Lubricants, p. 896.

ADOPTION OF TENTATIVE AS STANDARD WITHOUT REVISION

Committee D-4 recommends that the Tentative Specification for Hot-Mixed, Hot-Laid Asphaltic Concrete for Base and Surface Courses (**D 947 – 54 T**)[4] be approved for reference to letter ballot of the Society for adoption as standard without change.

ADOPTION OF TENTATIVE AS STANDARD WITH REVISION

Committee D-4 recommends jointly with Committee D-8 that the Tentative Methods of Sampling Bituminous Materials (**D 140 – 52 T**)[2] be approved for reference to letter ballot of the Society for adoption as standard with the following change:

Section 8(a). Liquid Materials.—In line 3, following the word "secured" add "after thoroughly mixing."

ADOPTION OF TENTATIVE REVISIONS AS STANDARD

Committee D-4 recommends that the following tentative revisions of standards be approved for reference to letter ballot of the Society for adoption as standard:

Definition of Terms Relating to Materials for Roads and Pavements (**D 8 – 52**),[2] tentative revision issued September 9, 1953.[5]

Method of Test for Distillation of Tars and Tar Products (**D 20 – 52**),[2] tentative revision issued September 9, 1953.[5]

Method of Test for Distillation of Cut-Back Asphaltic Products (**D 402 – 49**),[2] tentative revision issued September 9, 1953.[5]

Specifications for Crushed Stone, Crushed Slag, and Gravel for Water-Bound Macadam Base and Surface Courses of Pavements (**D 694 – 49**),[2] tentative revision issued June 1954.[4]

Specifications for Bituminous Mixing Plant Requirements (**D 995 – 53**),[5] tentative revision issued June 1953.[5]

REVISIONS OF STANDARDS, IMMEDIATE ADOPTION

Committee D-4 recommends for immediate adoption revisions in the following standards and accordingly asks for the necessary nine-tenths affirmative vote at the Annual Meeting in order that these revisions may be referred to letter ballot of the Society:

Standard Method of Test for Sieve Analysis of Mineral Filler (D 546 – 41):[2]

This method is referenced in Specifications D 947 – 54 T and D 978 – 54, and the grading requirements in neither of these specifications contain a control on the No. 80 sieve whereas they do contain a control on the No. 100 sieve. The following change is therefore recommended:

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[4] 1954 Supplement to Book of ASTM Standards, Part 3.

[5] 1953 Supplement to Book of ASTM Standards, Part 3.

Section 2(b).—In the Note, change "No. 80 (177-micron)" to read "No. 100 (149-micron)."

Standard Method of Test for Abrasion of Coarse Aggregate by Use of the Los Angeles Machine (C 131 – 51):[2]

Section 3(a).—Delete references to the cast iron spheres.

Standard Method of Test for Abrasion of Graded Coarse Aggregate by Use of the Deval Machine (D 289 – 53):[5]

Section 3(a).—Delete references to the cast iron spheres.

REAPPROVAL OF STANDARDS

Committee D-4 recommends that the following standard methods be reapproved:

Standard Method of:

Test for Amount of Material Finer than No. 200 Sieve in Aggregates (C 117 – 49),
Test for Sieve Analysis of Fine and Coarse Aggregates (C 136 – 46),
Test for Specific Gravity and Absorption of Coarse Aggregate (C 127 – 42),
Test for Specific Gravity and Absorption of Fine Aggregate (C 128 – 42), and
Sampling Stone, Slag, Gravel, Sand, and Stone Block for Use as Highway Materials (D 75 – 48).

STANDARDS CONTINUED WITHOUT REVISION

Committee D-4 recommends that the following standard specifications and methods be continued as standard without revision. All of these standards have been reviewed by the subcommittees responsible for their development and revision, and the standards have been found to be satisfactory in accordance with present practice:

Standard Specifications for:

Tar (D 490 – 47),
Cut-Back Asphalt, Rapid-Curing Type (D 597 – 46),
Cut-Back Asphalt, Medium-Curing Type (D 598 – 46),
Materials for Cement Grout Filler for Brick and Stone Block Pavements (D 57 – 20),
Materials for Sand-Cement Bed for Brick and Block Pavements (D 58 – 37),
Coal-Tar Pitch for Stone Block Filler (D 112 – 30),
Recut Granite Block for Pavements (D 131 – 39),
Granite Block for Durax Pavements (D 132 – 39),
Asphalt Filler for Brick Pavements (D 241 – 43),
Calcium Chloride (D 98 – 48),
Sodium Chloride (D 632 – 43),
Preformed Expansion Joint Fillers for Concrete, Nonextruding and Resilient Types (D 544 – 49),

Standard Method of Test for:

Residue of Specified Penetration (D 243 – 36),
Water in Petroleum Products and Other Bituminous Materials (D 95 – 46),
Distillation of Cut-Back Asphaltic Products (D 402 – 49),
Ductility of Bituminous Materials (D 113 – 44),
Softening Point of Bituminous Materials, Ring-and-Ball Method (D 36 – 26),
Softening Point of Tar Products, Cube-in-Water Method (D 61 – 38),
Hot Extraction of Asphaltic Materials and Recovery of Bitumen by the Modified Abson Procedure (D 762 – 49),
Float Test for Bituminous Materials (D 139 – 49),
Abrasion of Rock by Use of the Deval Machine (D 2 – 33),
Toughness of Rock (D 3 – 18),
Proportion of Bitumen Soluble in Carbon Tetrachloride (D 165 – 42),
Sulfonation Index of Road Tars (D 872 – 48),
Sampling and Testing Calcium Chloride (D 345 – 48),
Preformed Expansion Joint Fillers for Concrete, Nonextruding and Resilient Types (D 545 – 49),
Moisture-Density Relations of Soil-Cement Mixtures (D 558 – 44),
Wetting-and-Drying Test of Compacted Soil-Cement Mixtures (D 559 – 44),
Freezing-and-Thawing Test of Compacted Soil-Cement Mixtures (D 560 – 44), and
Cement Content of Soil-Cement Mixtures (D 806 – 47).

TENTATIVES CONTINUED WITHOUT REVISION

Committee D-4 recommends that the following tentative specifications and methods be continued as tentative without revision. In all cases, subcommittees responsible for these tentatives consider that further work is required on them before recommending their adoption as standard. In most instances, this further work is in progress.

Tentative Specifications for:

- Asphalt Cement for Use in Pavement Construction (D 946 - 47 T),
- Preformed Expansion Joint Fillers for Concrete (Non-extruding and Resilient Types) (D 544 - 52 T),
- Concrete Joint Sealer, Hot-Poured Elastic Type (D 1190 - 52 T),
- Materials for Soil-Aggregate Subbase, Base, and Surface Courses (D 1241 - 52 T),

Tentative Method of Test for:

- Vacuum Distillation of Liquid and Semi-Solid Asphaltic Materials to Obtain a Residue of Specified Penetration (D 1189 - 52 T),
- Loss on Heating of Oil and Asphaltic Compounds (D 6 - 39 T),
- Concrete Joint Sealers (D 1191 - 52 T),
- Moisture Density Relations of Soils (D 698 - 42 T),
- Soil-Bituminous Mixtures (D 915 - 47 T), and
- Shear Strength of Flexible Road Surfaces, Subgrades, and Fills by the Burggraf Shear Apparatus (D 916 - 47 T).

TENTATIVE REVISION CONTINUED WITHOUT CHANGE

Committee D-4 recommends that the tentative revision issued February 15, 1952, of the Standard Specifications for Sodium Chloride (**D 632 - 43**) be continued without change.

EDITORIAL CHANGE

Committee D-4 recommends that the Volume Correction Table for Tar and Coal-Tar Pitch (**D 633 - 44**)[2] be editorially revised as follows:

In the table in the second paragraph, change the heading "Group Number" to "Group."

In the volume correction tables, in the Note, and in the corresponding tables of multipliers, change "OOO" to "A," "OO" to "B," and "O" to "C."

The recommendations in this report have been submitted to letter ballot of the committee, the results of which will be reported at the Annual Meeting.[6]

ACTIVITIES OF SUBCOMMITTEES

Subcommittee B-2, Physical Tests for Compressed Bituminous Mixtures (L. F. Rader, chairman) is actively engaged in the preparation of a method of test for stability and flow values by means of the Marshall test apparatus. Work is also under way on the preparation of a method of test by the Hveem stabilometer and cohesiometer and on a method of compaction of bituminous specimens by the kneading compactor.

Subcommittee B-3, Distillation (J. W. Donegan, chairman) has been actively engaged in a review of all standards under its jurisdiction. Particular attention is being given to possible revisions of the Method of Test for Water in Petroleum Products and Other Bituminous Materials (D 95 - 46) and Method of Test for Distillation of Cut-Back Asphaltic Products (D 402 - 49).

Subcommittee B-6 on Extraction and Recovery of Constituents from Bituminous Mixtures (R. R. Thurston, chairman) is actively engaged in a study of various extraction methods in anticipation of making possible improvements in these ASTM procedures.

Subcommittee B-7 on Viscosity and Float Test (C. A. Benning, chairman).—A method of test of Engler specific viscosity of road tars is now under consideration. Additional work is required, however, before the subcommittee is able to make definite recommendations.

Subcommittee B-9 on Size of Aggregate (Fred Hubbard, chairman).—An active study has been made of all standards under the jurisdiction of this subcommittee, resulting specifically in certain recommendations for changes of sieve sizes in Method D 546 as noted elsewhere in this report.

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[6] The letter ballot vote on these recommendations was favorable; the results of the vote are on record at ASTM Headquarters.

Subcommittee B-12 on Structural Properties of Mineral Aggregate (Stanton Walker, chairman).—A review of standards under the jurisdiction of this subcommittee was completed, and a study is now in progress to develop a method of test for flat and elongated particles in aggregates.

Subcommittee B-14 on Specific Gravity of Fine and Coarse Aggregates (H. T. Williams, chairman).—An active study is now in progress to determine better ways and means of determining the "effective" specific gravity of aggregates in bituminous paving mixtures. It is indicated that current procedures do not always provide reliable results, and the subcommittee is attempting to devise a more appropriate test method for this purpose.

Subcommittee B-15 on Sampling Road Materials (R. E. Britton, chairman).—In addition to an active review of standards under its jurisdiction, this subcommittee has given particular attention to Method D 140 - 52 T, submitting definite recommendations on an editorial change and adoption of these methods as standard, as noted elsewhere in this report.

Subcommittee B-16 on Setting Qualities of Bituminous Materials (A. B. Cornthwaite, chairman) has been quite active through a task force which has been investigating the use of a rolling-ball apparatus as a potential method of determining the rate of setting of bituminous materials.

Subcommittee B-17 on Emulsion Tests (R. R. Thurston, chairman).—A task force within this subcommittee is engaged in cooperative work on certain of the emulsion tests. The work has not yet progressed to the point of making specific recommendations.

Subcommittee B-19 on Accelerated Tests for Durability of Bituminous Materials (D. C. Taylor, chairman).—The principal activity of this subcommittee pertains to a study of the "Thin Film Oven Test" as one potential method of indicating the durability of bituminous materials. A task group has conducted cooperative tests on this method and these cooperative tests are being continued.

Subcommittee B-24 on Penetration Test (J. Y. Welborn, chairman) is presently giving consideration to certain proposed revisions in the Method of Test for Penetration of Bituminous Materials (D 5 - 52). Consideration is being given to a standardization of a needle-ferrule assembly and to the provision of tolerances on total load and test temperature in the method. Also under consideration is the problem of repeatability and reproducibility of this test.

Subcommittee B-26 on Effect of Water on Bituminous Coated Aggregates (C. M. Hewett, chairman).—Several methods of evaluating the percentage of retained bituminous coating on aggregates are under active study including flame photometry procedures, radioactive tracer elements, and other methods.

Subcommittee C-4 on Emulsified Asphalts (C. E. Proudley, chairman) is engaged in work on specifications for a medium setting emulsified asphalt. Specific objectives have been established and a task group is actively at work on this subject.

Subcommittee C-10 on Plant-Mix Bituminous Surfaces and Bases (Fred Hubbard, chairman).—In addition to an active review of standards under its jurisdiction, this subcommittee has recently made specific recommendations on changes in grading requirements for Specification D 242 as noted elsewhere in this report.

Subcommittee C-12 on Bituminous Surface Treatments (J. O. Izatt, chairman) prepared the draft of the proposed revisions of the Tentative Specifications for Crushed Stone, Crushed Slag, and Gravel for Single, Double, and Multiple Bituminous Surface Treatments, and the proposed Tentative Recommended Practice for Quantities of Materials for Bituminous Surface Treatments, noted elsewhere in this report.

Subcommittee D-1 on Calcium Chloride and Sodium Chloride for Use as Road Materials (H. F. Clemmer, chairman) has prepared a revision of the Specification for Calcium Chloride to replace the existing Standard Specification D 98 – 48. The proposed specification is being given further consideration.

Subcommittee D-2 on Highway Traffic Markers (N. G. Smith, chairman) is now giving consideration to the development of specifications and methods of tests for permanent or semi-permanent traffic markers other than paints.

Subcommittee D-3 on Expansion Joint Materials (H. F. Clemmer, chairman) is engaged in a series of cooperative tests on expansion joint material to check the adequacy and accuracy of existing methods of test. Consideration is being given to the expansion of Specification D 544 to include preformed fillers for use in structures. The Executive Subcommittee of Committee D-4 has advised the subcommittee that its work should be limited to expansion joint materials for highway structures.

Joint Subcommittee of Committees D-4 and D-18 on Tests and Specifications for Stabilized Soils (H. F. Clemmer, chairman) circulated to Committee D-4 a proposed revision of Table I of Tentative Specifications for Materials for Soil-Aggregate Subbase, Base, and Surface Courses (D 1241 – 52 T) and a proposed new tentative method of testing soils for water-soluble constituents. Additional refinements may be required before recommending them to Committee D-4.

This report has been submitted to letter ballot of the committee, which consists of 155 members; 125 members returned their ballots, of whom 112 have voted affirmatively and 0 negatively.

Respectfully submitted on behalf of the committee,

C. W. ALLEN,
Chairman.

J. M. GRIFFITH,
Secretary.

REPORT OF COMMITTEE D-5

ON

COAL AND COKE*

Committee D-5 on Coal and Coke held two meetings during the year: in Chicago, Ill., on June 15 and 16, 1954, and on January 30 to February 1, 1955, in Cincinnati, Ohio.

During the year, one member was added to the committee, one member resigned, and two members died, resulting in a total voting membership of 59, of whom 16 are classified as producers, 20 as consumers, and 23 as general interest members.

At the June, 1954, meeting of the Advisory Subcommittee, W. A. Selvig and O. W. Rees were appointed as the U. S. delegates to the Fourth Meeting of Technical Committee 27 on Solid Mineral Fuels, of the International Organization for Standardization, scheduled for June 6 to 10, 1955, in Stockholm, Sweden.

TENTATIVE REVISION OF STANDARDS

Committee D-5 recommends the following tentative revision of the Standard Methods of Laboratory Sampling and Analysis of Coal and Coke (**D 271 – 48**):[1]

Sections 37 and 38.—Replace with the following Sections 38 to 42.

NITROGEN

38. *Outline of Method.*—The determination of nitrogen shall be made by either the Kjeldahl-Gunning or the alternate methods described herein. In these procedures nitrogen is converted into ammonium salts by destructive digestion of the sample with a hot, catalyzed mixture of concentrated sulfuric acid and potassium sulfate. These salts are subsequently decomposed in a hot alkaline solution from which the ammonia is recovered by distillation, and finally determined by alkalimetric or acidimetric titration.

39. *Apparatus.*—The apparatus required shall consist of the following:

(*a*) *Digestion Unit.*—An electrical heater of approximately 500-w minimum rating or a gas burner of comparable capacity; either type of heater shall be provided with adequate means of control to maintain digestion rates as described in Section 41(*b*) (Note 1). Commercially made, multiple-unit digestion racks provided with fume exhaust ducts may be used.

NOTE 1.—If commercially made electrical heaters are used, auxiliary voltage control equipment, such as an autotransformer, may be needed to maintain the specified rates of digestion and distillation.

(*b*) *Distillation Unit.*—An electrical heater or gas burner as described in Paragraph (*a*); either type shall be provided with adequate means of control to maintain distillation rates as described in Section 41 (Note 1). Commercially made, multiple-unit distillation racks provided with water-cooled glass or block tin condensers may be used.

(*c*) *Condenser.*—A glass condenser, water-cooled, having a minimum jacket length of 500 mm. This apparatus is not ordinarily required when a commercially made distillation rack is used.

(*d*) *Kjeldahl Digestion Flask,* of Pyrex glass, having a capacity of 500 or 800 ml.

(*e*) *Kjeldahl Connecting Bulb,* cylindrical type, 45 mm in diameter by 100 mm long, or larger, with curved inlet and outlet tubes.

(*f*) *Erlenmeyer Flask,* having a capacity of 250 or 300 ml.

(*g*) *Glass Connecting Tube,* approximately 10 mm in outside diameter by 200 mm long.

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* Presented at the Fifty-eighth Annual Meeting of the Society, June 26–July 1, 1955.

[1] 1952 Book of ASTM Standards, Part 5.

(*h*) *Rubber Tubing*, short piece.

40. *Reagents.*—All reagents referred to herein shall conform to the specifications for reagent-grade chemicals established by the Committee on Analytical Reagents of the American Chemical Society, or be otherwise certified as suitable for Kjeldahl determinations.

(*a*) *General Reagents Needed:*

(*1*) *Sulfuric Acid*, (*sp gr 1.84*), concentrated.

(*2*) *Potassium Sulfate*, crystals.

(*3*) *Mercury*, metal (Note 2).

(*4*) *Potassium Permanganate*, crystals.

(*5*) *Alkali Solution.*—Prepare a solution containing 0.8 per cent (by wt) of K_2S and 33 per cent (by wt) of NaOH in distilled water. The use of appropriate amounts of Na_2S or KOH may be substituted for the above, if desired (Note 2, Paragraph (*c*)).

(*6*) *Zinc*, metal, mossy, or granular.

(*7*) *Ethanol* (*95 per cent*), or methanol,

(*8*) *Sucrose*, National Bureau of Standards primary-standard grade.

NOTE 2.—Other satisfactory and permissible catalysts for the digestion, together with the quantities of K_2SO_4 required in their use, are as follows:

(*a*) Five grams of a mixture containing 32 parts by wt of K_2SO_4, 5 parts by wt of $HgSO_4$, and 1 part by wt of selenium.

(*b*) Three-tenths gram of mercuric selenite ($HgSeO_3$) with 7 to 10 g of K_2SO_4.

(*c*) Three-tenths gram of cupric selenite dihydrate ($CuSeO_3 \cdot 2H_2O$) with 7 to 10 g of K_2SO_4. When this mixture is used, the addition of a sulfide to the alkali solution is not necessary.

(*b*) *Specific Reagents for Kjeldahl-Gunning Method:*

(*1*) *Sulfuric Acid* (*approximately 0.2 N*). This solution need not be standardized against a primary standard.

(*2*) *Methyl Red Indicator* (*0.04 to 0.1 per cent* (*wt per unit vol*)), in 95 per cent ethanol or methanol. Bromocresol green solutions of equal concentrations may be used.

(*3*) *Sodium Hydroxide* (*0.1 to 0.2 N*), accurately standardized against a primary standard.

(*c*) *Specific Reagents for Alternate Method:*

(*1*) *Boric Acid Solution.*—Prepare a 5 per cent (by wt) solution by dissolving an appropriate amount of H_3BO_3 in boiling, distilled water; allow to cool before use.

(*2*) *Sulfuric Acid* (*0.1 to 0.2 N*), accurately standardized against a primary standard; HCl of similar concentration may be substituted.

(*3*) *Mixed Indicator Solution.*—Prepare a solution containing 0.125 per cent (wt per unit vol) methyl red and 0.083 per cent (wt per unit vol) methylene blue in 95 per cent ethanol or methanol. Prepare a fresh solution at bimonthly intervals.

41. *Kjeldahl-Gunning Method:*

(*a*) *Sample.*—Approximately 1 g (weighed to the nearest 1 mg) of air-dry sample ground to pass a No. 60 (250-micron) or finer sieve, shall be weighed into a weighing scoop. In the case of coke and anthracite, grinding the sample to pass a No. 200 (74-micron) or finer sieve is recommended.

(*b*) *Procedure:*

(*1*) Carefully transfer the sample into a 500 or 800-ml Kjeldahl flask containing 7 to 10 g of K_2SO_4 and 0.6 to 0.8 g of mercury (Note 2). Add 30 ml of concentrated H_2SO_4 to the mixture by pouring it down the neck of the flask with rotation, in order to wash any adherent sample material into the mixture. Swirl the contents of the flask several times to insure thorough mixing and wetting of the sample. Incline the flask at an angle of 45 to 60 deg on the digestion heater in a fume hood (Note 3), and heat the contents to boiling; controlling the heat input in such a manner that the H_2SO_4 vapors condense no more than half-way up the neck of the flask (Note 1). Continue the boiling until all sample particles are oxidized, as evidenced by a nearly colorless solution, or for at least 2 hr after the solution has reached a straw-colored stage. The total time of digestion will require 3 to 4 hr, except in the case of coke and anthracite, which may require 12 to 16 hr (Note 4). When the digestion is completed and the solution has cooled, a few crystals of $KMnO_4$ may be added to insure complete oxidation; further heating may be necessary to destroy the excess permanganate and decolorize the solution.

NOTE 3.—When fume exhaust ducts or hoods are not available a Hengar tube may be inserted in the neck of the flask.

NOTE 4.—Addition of 0.1 g of chromic anhydride (CrO_3) to the digestion mixture has been found very helpful in reducing the time of digestion for coke.

(*2*) Dilute the cooled digestion mixture to about 300 ml with cold water, and remove any heat of dilution by cooling with water. Meanwhile, measure into the 250- or 300-ml Erlenmeyer flask, exactly 20.0 ml of H_2SO_4 (approximately 0.2 *N*) and add 6 drops of methyl red or bromocresol green indicator solution. Attach the glass connecting tube to the discharge end of the condenser, using the short piece of rubber tubing as a seal. Incline the Erlenmeyer flask at a suitable angle, and insert this tube so that the end is immersed to the maximum depth in the acid. Add 1 to 2 g of granular zinc to the mixture in the Kjeldahl flask (two or three small pieces if mossy zinc is used), and slowly add 100 ml of the alkali solution so that it forms a distinct layer under the acid solution. This may be accomplished by inclining the flask at an angle of 45 to 60 deg and pouring the alkali solution down the neck. Failure to maintain discrete layers during this operation may lead to loss of ammonia. Quickly connect the flask to the distilling condenser through the Kjeldahl connecting bulb, and then swirl the contents to promote thorough mixing.

(*3*) Bring the contents of the Kjeldahl flask to a boil carefully, in order to avoid violent bumping, and then distill the ammonia over into the acid solution in the Erlenmeyer flask. Continue the distillation at a maximum rate of approximately 350 ml per hr until 150 to 175 ml of distillate have been collected. Discontinue the boiling, and remove the glass connecting tube from the condenser and Erlenmeyer flask. Rinse the tube with distilled water, collecting the washings in the Erlenmeyer flask, and then back-titrate the excess acid with standard alkali.

(*4*) Run a blank determination in exactly the same manner as described above, using approximately 1 g of sucrose (weighed to the nearest milligram) as the sample material (Note 5).

NOTE 5.—Blank determinations must be made to correct for nitrogen from sources other than the sample. A blank determination shall be made whenever a new batch of any one reagent is used in the analysis.

(*5*) Calculate the percentage of nitrogen in the sample as follows:

$$\text{Nitrogen, per cent} = \frac{[(\text{ml base})_B - (\text{ml base})_S] \times N \times 0.014}{W} \times 100$$

where:

B = blank,
S = sample,
N = normality of the base, and
W = weight of the sample in grams.

42. *Alternate Method:*

(*a*) *Sample.*—The sample shall be as described in Section 41(*a*).

(*b*) *Procedure:*

(*1*) Digest the sample as described in Section 41(*b*)(*1*).

(*2*) Dilute and cool the digestion mixture as described in Section 41(*b*)(*2*). Add to the 250- or 300-ml Erlenmeyer flask approximately 20 ml of H_3BO_3 solution and 6 drops of mixed indicator solution, instead of the H_2SO_4 and methyl red indicator solution used in Section 41(*b*)(*2*). Then proceed exactly as described in the remainder of Section 41(*b*) (*2*).

(*3*) Distill the ammonia into the H_3BO_3 solution exactly as described in Section 41(*b*)(*3*), and finally titrate the ammonia with standard acid.

(*4*) Run a blank determination in exactly the same manner as described above, using approximately 1 g (weighed to the nearest milligram) of sucrose as the sample material (Note 5).

(*5*) Calculate the percentage of nitrogen in the sample as follows:

$$\text{Nitrogen, per cent} = \frac{[(\text{ml acid})_S - (\text{ml acid})_B] \times N \times 0.014}{W} \times 100$$

where:

S = sample.
B = blank,
N = normality of the acid, and
W = weight of the sample in grams.

The recommendations in this report have been submitted to letter ballot of the committee, the results of which will be reported at the Annual Meeting.[2]

STANDARDS CONTINUED WITHOUT REVISION

The following 20 standards have been published for six years or longer without revision. Except as noted in the subsequent summary of subcommittee activities, all are considered to be in accord with current practice. All are recommended for continuance in their present form with the understanding that work now in progress may in some cases result in early recommendations for revision:

Standard Method of:

Drop Shatter Test for Coke (D 141 – 48),
Test for Volume of Cell Space of Lump Coke (D 167 – 24),

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[2] The letter ballot vote on these recommendations was favorable; the results of the vote are on record at ASTM Headquarters.

Sampling and Fineness Test of Powdered Coal (D 197 - 30),
Test for Cubic Foot Weight of Crushed Bituminous Coal (D 291 - 29),
Test for Cubic Foot Weight of Coke (D 292 -29),
Test for Size of Anthracite (D 310 - 34),
Test for Sieve Analysis of Crushed Bituminous Coal (D 311 - 30),
Sampling Coke for Analysis (D 346 - 35),
Test for Screen Analysis of Coal (D 410 - 38),
Designating the Size of Coal from Its Screen Analysis (D 431 - 44),
Drop Shatter Test for Coal (D 440 - 49),
Tumbler Test for Coal (D 441 - 45),
Sampling Coals Classed According to Ash Content (D 492 - 48), and
Test for Index of Dustiness of Coal and Coke (D 547 - 41).

Standard Specifications for:

Gas and Coking Coals (D 166 - 24),
Classification of Coals by Rank (D 388 - 38), and
Classification of Coals by Grade (D 389 - 37).

Standard Definitions of:

Terms Relating to Coal and Coke (D 121 - 30),
Terms Gross Calorific Value and Net Calorific Value of Fuels (D 407 - 44), and
Commercial Varieties of Bituminous and Subbituminous Coals (D 493 - 39).

ACTIVITIES OF SUBCOMMITTEES

Subcommittee II on Nomenclature and Definitions (C. H. Sawyer, chairman) is discussing definitions of various types of coke and various types of moisture. The coke industry will be asked for positive recommendations for definitions of various types of coke. Definitions of various types of moisture require further study, and the subcommittee hopes to resolve differences of opinion at the next meeting, scheduled for June, 1955.

Subcommittee XV on Plasticity and Swelling of Coal (Michael Perch, chairman).—The subcommittee has been engaged in the cooperative investigation of the Arnu dilatometer in response to a request that a laboratory coking or caking test be available for possible use in conjunction with the present Standard Specification for Classification of Coals by Rank (D 388–38) in a manner similar to that proposed by the Classification Working Party of the Economic Commission for Europe, Coal Committee. Good reproducibility is secured in the Arnu test by one laboratory between duplicates as well as between two different operators. Interlaboratory agreement was poor, due possibly to equipment differences. Although significant correlations were found between volatile matter content, Arnu maximum dilation, and Gieseler maximum fluidity, the consensus was that further work on the Arnu test should be held in abeyance in favor of extra effort toward standardization of the Gieseler test. A second-draft proposal for the Gieseler method has been distributed for comments and criticism.

Subcommittee XXI on Methods of Analysis (O. W. Rees, chairman).—Section A on Proximate Analysis is reviewing a third-draft proposal on Moisture Holding Capacity of Coal at 97 per cent Relative Humidity and 30 C. Work is continuing on comparisons of volatile matter determination by ASTM standard and modified procedures, as well as by the British single-crucible and the French double-crucible methods.

Section B on Ultimate Analysis prepared the tentative revision of the Standard Method of Laboratory Sampling and Analysis of Coal and Coke (D 271 - 48) relating to the procedure for nitrogen determination. Revision of the method for the determination of oxygen has been undertaken and the section hopes to submit this to ballot in the coming year.

Section C on Miscellaneous Analysis is drafting a proposed revision of the ash-fusion determination of Method D 271–48 (Sections 28–31), and has undertaken as a new assignment the study of determination of carbonate carbon by gravimetric and pressometric methods.

Subcommittee XXII on Physical Tests of Coke (B. P. Mulcahy, chairman).—Working sections have been formed to review Standard Methods D167 – 24 D 141 – 48, and D 239 – 50, covering volume of cell-space, drop shatter test, and size-consist, respectively. The subcommittee hopes to complete a method for cubic foot weight of coke based on calculation from size-consist and apparent specific gravity.

Subcommittee XXIII on Sampling (W. M. Bertholf, chairman) was formed to handle all sampling problems which previously had been distributed among Subcommittees XIII, XXI, and XXII. Three sections of Subcommittee XXIII have been formed: Section 1 on Sampling of Coal, Section 2 on Sampling of Coke, and Section 3 on Sample Preparation. In addition to continuing the work previously handled by the Mechanical Sampling Section of Subcommittee XIII, Subcommittee XXIII agreed to review sampling methods for moisture content, methods of sampling coke, and methods for preparation and reduction of both coal and coke samples for the laboratory.

This report has been submitted to letter ballot of the committee, which consists of 59 voting members; 57 members returned their ballots, of whom 55 have voted affirmatively and 0 negatively.

Respectfully submitted on behalf of the committee,

W. W. ANDERSON,
Chairman.

O. P. BRYSCH,
Secretary.

REPORT OF COMMITTEE D-6

ON

PAPER AND PAPER PRODUCTS*

Committee D-6 on Paper and Paper Products held two meetings during the year: on June 16, 1954, in Chicago, Ill., and on February 25, 1955, in New York City. The Advisory and other subcommittees held meetings in conjunction with the main committee.

At the present time the committee consists of 91 members, of whom 78 are voting members; 34 are classified as producers, 25 as consumers, and 32 as general interest members.

REVISION OF TENTATIVE

The committee recommends that the Tentative Method of Test for Fiber Analysis of Paper and Paperboard (**D 1030 - 49 T**)[1] be revised as appended hereto.[2]

TENTATIVE REVISION OF STANDARD

The committee recommends tentative revisions of the Standard Method of Test for Resistance of Paper to Passage of Air (**D 726 - 48**)[1] in the form of the completely revised tentative method appended hereto.[2] It is planned that when adopted as standard this complete revision will replace the existing standard.

REVISION OF STANDARD AND REVERSION TO TENTATIVE

The committee recommends that the Standard Method of Test for Water Resistance of Paper, Paperboard, and Other Sheet Materials by the Dry-Indicator Method (**D 779 - 54**)[1] be revised as follows and reverted to tentative status:

Section 1.—Add the following sentence to the end of this section: "This method is applicable only to papers requiring not more than 60 min for the test."

ADOPTION OF TENTATIVE AS STANDARD WITH REVISION

The committee recommends that the Tentative Method of Test for Moisture in Paper, Paperboard, and Paperboard and Fiberboard Containers (**D 644 - 53 T**)[3] be approved for reference to letter ballot of the Society for adoption as standard with the following revision:

Section 2(d).—A chemical balance sensitive to 1 mg for weighing specimens of 2 g and under, and sensitive to 0.05 per cent of the original weight of the specimen for larger specimens.

REVISION OF STANDARD, IMMEDIATE ADOPTION

The committee recommends for immediate adoption the following revision of the Standard Method of Test for Wire and Felt Sides of Paper (**D 725 - 45**),[1] and accordingly asks for the necessary nine-tenths affirmative vote at the Annual Meeting in order that the revision may be referred to letter ballot of the Society:

Section 5.—Delete this section.

REAPPROVAL OF STANDARDS

The committee recommends that the following standards, which have stood for six or more years without revision, be reapproved as standard with editorial changes as indicated:

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* Presented at the Fifty-eighth Annual Meeting of the Society, June 26–July 1, 1955.

[1] 1952 Book of ASTM Standards, Part 7.

[2] The revised tentative appears in the 1955 Book of ASTM Standards, Part 7.

[3] 1953 Supplement to Book of ASTM Standards, Part 7.

Standard Method of Test for Ash Content of Paper and Paper Products (D 586 – 42):[1]

Section 1.—Delete from this section all but the first sentence.

New Section.—Designate as new Section 2 on Significance of Test the material deleted from the present scope, and renumber the present Section 2 and subsequent sections accordingly.

Standard Method of Test for Casein in Paper (Qualitative) (D 587 – 42).[1]

Standard Method of Test for Alpha-, Beta-, and Gamma-Cellulose in Paper (D 588 – 42):[1]

New Section.—Add a new Section 2 on Significance of Test, and renumber the present Section 2 and subsequent sections accordingly:

2. There are several schools of thought as to the value of determining the alpha cellulose in paper. Some believe that chemical stability with respect to permanence of paper is related to the alpha cellulose present, contending that the higher this is, the more permanent the paper. Others state that in some instances considerable fiber deterioration may occur before there is an appreciable loss of alpha cellulose. Still others state that this test is significant only when comparing the alpha cellulose of fibers of the same kind and origin.

Standard Method of Test for Paraffin Content of Waxed Paper (D 590 – 42):[1]

New Section.—Add a new Section 2 on Significance of Test, and renumber the present Section 2 and subsequent sections accordingly:

2. This method measures the amount of wax required to saturate a paper without producing any surface film. The results may be used for comparing two or more samples, to judge their suitability for wet waxing, dry waxing, or laminating, or to judge the performance of saturating machines. The method is of chief interest to converters or laminators as a screening test or for control purposes.

Standard Method of Test for Adhesiveness of Gummed Tape (D 773 – 47):[1]

Section 1.—Delete the Note from this section.

New Section.—Designate as new Section 2 on Significance of Test the Note deleted from Section 1.

Standard Method of Test for Absorption by Bibulous Papers of Water and Writing Ink (D 824 – 47):[1]

New Section—Add a new Section 2 on Significance of Test, and renumber the present Section 2 and subsequent sections accordingly:

2. This test is significant in determining the amount of ink which will be absorbed by blotting paper or the amount of water which will be absorbed by paper towels. This is important with respect to the drying ability of the toweling and the amount of toweling needed for drying.

Standard Method of Test for Degree of Wet Curl of Paper (D 826 – 47):[1]

Section 1.—Delete the second and third sentences and the Note.

New Section.—Add a new Section 2 on Significance of Test, and renumber the present Section 2 and subsequent sections accordingly:

2. This test to some degree signifies the amount of sizing such as rosin sizing and the tendency of the paper to curl with moisture changes. However, the factors out of which curling troubles grow are many and complex. It is therefore necessary to use caution in interpreting curling data obtained by this test in connection with certain types of curling troubles. A high wet curl test does not necessarily mean that the paper will, in every case, curl in practice.

Standard Method of Test for Bleeding Resistance of Asphalted Paper at Elevated Temperature (D 917 – 49):[1]

Section 1(a).—Delete the second sentence.

New Section.—Add a new Section 2 on Significance of Test, and renumber the present Section 2 and subsequent sections accordingly:

2. The bleeding resistance is significant as a measure of the ability of asphalt laminated or similarly treated case liners or baling paper to avoid staining the contents of a case or bundle.

Standard Method of Test for Copper Number of Paper and Paperboard (D 919 – 49):[1]

New Section.—Add a new Section 2 on Significance of Test, and renumber the present Section 2 and subsequent sections accordingly:

2. The copper number can be regarded as an index of those impurities in cellulose such as oxycellulose, hydrocellulose, lignin, and sugars which possess reducing properties. It is valuable for detecting changes accompanying deterioration and may, therefore, be considered as a test for indicating the permanence of paper. In parchment and grease-proof papers, copper number is considered to give an indication of the degree of parchmentizing.

Standard Method of Test for Crease Retention of Wrapping Paper (D 920 – 49):[1]

New Section.—Add a new Section 2 on Significance of Test, and renumber the present Section 2 and subsequent sections accordingly:

2. Creasing quality is an important property of wrapping paper to be used on some automatic machines. Here the value of the sheet as a wrapping material is determined by the ease with which the paper may be creased and its tendency to stay in the creased position when the sheet passes through a series of operations on the wrapping machines. For certain purposes, a paper having good creasing quality must not break at the creased line nor exhibit a tendency to spring back to the original position. The success of such operations as filling, gluing, heat sealing, and folding on wrapping machines is determined to a large extent by the creasing quality of the paper.

TENTATIVES CONTINUED WITHOUT REVISION

The committee recommends that the following eight tentative methods which have stood for two years without revision be continued as tentative:

Tentative Method of Test for:

Puncture and Stiffness of Paperboard, Corrugated and Solid Fiberboard (D 781 - 44 T),
Stretch of Paper and Paper Products Under Tension (D 987 - 48 T),
Water Vapor Permeability of Paper and Paperboard (D 988 - 51 T),
Chloride Content of Paper and Paper Products (D 1161 - 51 T),
Pinholes in Glassine and Other Greaseproof Papers (D 1221 - 52 T),
Contrast Gloss of Paper at 57.5 deg (D 1222 - 52 T),
Specular Gloss of Paper at 75 deg (D 1223 - 52 T), and
Dimensional Changes of Paper with Changes in Moisture Conditions (D 1270 - 53 T).

EDITORIAL CHANGES

The committee recommends that the following editorial changes be made in the Standard Method of Test for Hydrogen Ion Concentration (pH) of Buffered Paper Extracts (**D 778 – 50**)[1] in order to have it conform with the Tentative Method for Determination of pH of Aqueous Solutions with the Glass Electrode (E 70 – 52 T):

Section 3(a).—Change the first sentence to read: "There shall be two permissible types of meters (I and II), the particular choice depending upon the desired or specified accuracy in the determination." Change the third sentence to read: "For routine determinations of pH either type of meter may be used." In the fifth sentence, delete "of types I, II, and III."

Section 3(b).—At the end of the first sentence, delete the words "and not over 10 megohms for use with meters of type III."

Standard Method of Test for Edge Tearing Strength of Paper (D 827 – 47):[1]

Section 5.—Change Paragraph (*3*) to read "Rate of Loading."

The recommendations in this report have been submitted to letter ballot of the committee, the results of which will be reported at the Annual Meeting.[4]

ACTIVITIES OF SUBCOMMITTEES

Subcommittee I on Sampling and Conditioning (R. H. Lace, chairman) is continuing its work on a revision of the Method of Sampling Paper and Paper Products (D 585 - 42).

Subcommittee II on Chemical Test Methods (E. G. Ham, chairman) has completed the revision of the Method of Test for Fiber Analysis of Paper and Paperboard (D 1030 - 49 T) and has reviewed all methods under its jurisdiction. Five methods are being recommended for reapproval as standards. Work is being done which may lead to proposed revisions in Method of Test for Starch in Paper (D 591 - 42), Method of Qualitative Examination of Mineral Filler and Mineral Coating of Paper (D 686 - 48), Method for Quantitative Determination of Coating on Mineral - Coated Paper (D 687 - 44), Method of Test for Pentosans in Paper (D 688 - 44), Method of Test for Titanium Dioxide in Paper (D 921 - 49), and Method of Test for Chloride Content of Paper and Paper Products (D 1161 - 51 T).

Subcommittee III on Physical Test Methods for Paper (L. Price, chairman) prepared the complete revision of the Standard Method of Test for Resistance of Paper to Passage of Air (D 726 - 48) in cooperation with Subcommittee VIII of Committee D-9.

It has reviewed all methods under its jurisdiction and recommends that eight methods be reapproved as standards. The Standard Method of Test for Water Resistance of Paper, Paperboard, and Other Sheet Materials by the Dry-Indicator Method (D 779 - 54) is being recommended for reversion to tentative status because recent work shows the method to be of doubtful value when the time of test is more than a few minutes. Further work will be done to clarify the test.

Work is being done which may lead to proposed revisions in the Method of Test for Bursting Strength of Paper (D 774 - 46), Methods of Testing Analytical Filter Papers (D 981 - 51 T), Method of Test for Stretch of Paper and Paper Products (D 987 - 48 T), Methods of Test for Water Vapor Permeability of Paper and Paperboard (D 988 - 51 T), Method of Test for Pinholes in Glassine and Other Greaseproof Papers (D 1221 - 52 T), Method of Test for Contrast Gloss of Paper at 57.5 deg (D 1222 - 52 T), Method of Test for Specular Gloss of Paper at 75 deg (D 1223 - 52 T), and Method of Test for Dimensional Changes of Paper with Changes in Moisture Conditions (D 1270 - 53 T).

Subcommittee IV on Physical Test Methods for Container Board (W. B. Lincoln, Jr., chairman) is continuing its work on a revision of the Method of Test for Puncture and Stiffness of Paperboard, Corrugated and Solid Fiberboard (D 781 - 44 T). Work is also being done which may lead to a proposed revision of the Method of Test for Flat Crush of Corrugated Paperboard (D 1225 - 52 T). Work is under way on a wet bursting strength test, mold resistance, and corrugating medium testers.

Subcommittee VI—Editorial (L. S. Reid, chairman) is continuing its work of editing and preparing sections on significance of test for all new and revised methods.

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[4] The letter ballot vote on these recommendations was favorable; the results of the vote are on record at ASTM Headquarters.

This report has been submitted to letter ballot of the committee, which consists of 78 voting members; 43 members returned their ballots, all of whom have voted affirmatively.

Respectfully submitted on behalf of the committee,

W. R. WILLETS,
Chairman.

R. H. CARTER,
Secretary.

REPORT OF COMMITTEE D-7
ON
WOOD*

Committee D-7 on Wood met in Chicago, Ill., on March 14 and 15, 1955. The following subcommittee meetings preceded the meeting of the main committee: Subcommittee I on Specifications for Timber, Subcommittee IV on Wood Paving Blocks, Subcommittee VII on Wood Poles and Crossarms, and Subcommittee XV on Structural Fiberboards. A special feature of the meeting was the Golden Anniversary Dinner, commemorating fifty years of activity.

Sixteen applicants were elected to membership on the committee. There were three resignations.

REVISIONS OF TENTATIVES

The committee recommends that the following tentatives be revised as indicated and continued as tentative:

Tentative Methods of Static Tests of Wood Poles (D 1036 - 49 T):[1] Revise as appended hereto.[2]

Tentative Methods of Test for Alpha-Cellulose in Cellulosic Materials (D 1103 - 50 T):[1] Revise as appended hereto.[2]

Tentative Methods of Evaluating the Properties of Fiber Building Boards (D 1037 - 52 T):[1]

Title.—Change to read: "Methods of Test for Evaluating the Properties of Building Fiberboards."

Section 27.—Change the Note to read as follows:

NOTE.—This test is included because of the increased use of fiberboards where wood, plywood, or other materials are glued to the fiberboard. Tests in the soaked condition shall be made if the material is to be used under severe weather conditions.

Section 28.—Change the first and second sentences to read: "The test specimen shall be 2 in. (5 cm) square and the thickness shall be that of the finished board. Loading blocks of steel or aluminum alloy 2 in. (5 cm) square and 1 in. (2.5 cm) in thickness shall be effectively bonded with a suitable adhesive (Note) to the 2-in. (5 cm) square faces of the specimen as shown in Fig. 5, which is a detail of the specimen and loading fixtures."

Change the Note to read as follows:

NOTE.—Any suitable adhesive that provides an adequate bond may be used for bonding the fiberboard specimen to the loading blocks. Epoxy resins are recommended as a satisfactory bonding agent. The pressure required to bond the blocks to the specimen will depend on the density of the board and the adhesive used, and should not be so great as to measurably damage the fiberboard. The resulting bond shall be at least as strong as the cohesive strength of the material perpendicular to the plane of the fiberboard.

Section 33.—Add the following two sentences to the end of the Section: "When general information is desired the 6d common nail or its equivalent should be used. For special applications, however, this procedure is adaptable to other sizes and types of fasteners."

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* Presented at the Fifty-eighth Annual Meeting of the Society, June 26–July 1, 1955.

[1] 1952 Book of ASTM Standards, Part 4.

[2] The revised tentative appears in the 1955 Book of ASTM Standards, Part 4.

Section 36.—Add the following sentence to the end of the Section: "For other types of fasteners, such as staples, modification of the stirrup may be necessary."

Section 39.—Add the following two sentences to the end of the Section: "When general information is desired, the 6d common nail or its equivalent should be used. For special applications, however, this procedure is adaptable to other sizes and types of fasteners."

Section 40.—Number the present Note as "1" and add a new Note 2 as follows:

> NOTE 2.—Where the use of a particular nail or fastener requires less than $\frac{1}{2}$ in. of shank projecting above the surface, then only sufficient length shall be left to permit engagement in the testing assembly.

Section 43.—Add the following sentence to end of paragraph: "For other types of fasteners, such as staples, modification of the loading fixture may be necessary."

Section 61(a).—In the next to the last sentence change "97^{+3}_{-5} per cent" to "90 ± 5 per cent."

Add new Note at the end of Section 61(*a*) as follows:

> NOTE.—Where values of linear expansion associated with exposure to a greater humidity change are desired, equilibrium at a relative humidity of 30 ± 1 per cent may be used for the lower humidity condition rather than the 50 per cent specified in Section 61. The report shall state the actual humidity conditions used.

Section 61(b).—Delete the note at the end of the Section.

Tentative Methods of Test for Methoxyl Groups in Wood and Related Materials (D 1166 – 51 T):[1]

Section 1.—Change to read as follows:

> 1. This method is intended for the determination of methoxyl groups in wood and related materials (1 to 7).[3] The method is applicable to wood sawdust and, by suitable adjustment in size of the test specimen, to fractions isolated from wood and lignin.

ADOPTION OF TENTATIVE AS STANDARD WITHOUT REVISION

The committee recommends that the Tentative Specification for Round Timber Piles (**D 25 – 54 T**)[3] be approved for reference to letter ballot of the Society for adoption as standard without change.

REVISION OF STANDARD, IMMEDIATE ADOPTION

The committee recommends for immediate adoption revisions of the Standard Specifications for Wood Block Flooring, End-Grain, Creosoted, for Interior Use (**D 1031 – 51**)[1] as appended hereto[4] and accordingly asks for the necessary nine-tenths affirmative vote at the Annual Meeting in order that the revisions may be referred to letter ballot of the Society.

STANDARDS CONTINUED WITHOUT REVISION

The committee recommends that the following standards be continued in their present status:

Standard Methods of:

Sampling and Testing Creosote (D 38 – 33),
Test for Coke Residue of Creosote (D 168 – 30),
Static Tests of Timbers in Structural Sizes (D 198 – 27),
Test for Distillation of Creosote (D 246 – 49),
Test for Benzene-Insoluble Matter in Creosote (D 367 – 49),
Test for Specific Gravity of Creosote (D 368 - 33),
Test for Specific Gravity, 38/15.5C of Creosote Fractions (D 369 – 33),
Test for Water in Creosote (D 370 – 33), and
Test for Tart Acids in Creosote and Creosote-Coal Tar Solutions (D453 – 41).

Standard Definitions of Terms Relating to:

Timber (D 9 – 30), and Timber Preservatives (D 324 – 41).

Volume and Specific Gravity Correction Tables for:

Creosote and Coal Tar (D 347 – 33).

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[3] 1954 Supplement to Book of ASTM Standards, Part 4.

[4] The revised standard appears in the 1955 Book of ASTM Standards, Part 4.

TENTATIVES CONTINUED WITHOUT REVISION

The committee recommends that the following tentative specifications and methods be continued in their present status pending further study:

Tentative Specifications for:

Copperized Chromated Zinc Chloride (D 1271 - 53 T),
Pentachlorophenol (D 1272 - 53 T),

Tentative Methods of:

Chemical Analysis of Copperized Chromated Zinc Chloride (D 1273 - 53 T),
Chemical Analysis of Pentachlorophenol (D 1274 - 53 T),
Establishing Structural Grades of Lumber (D 245 - 49 T),
Test for Ash in Wood (D 1102 - 50 T),
Test for Holocellulose in Wood (D 1104 - 50 T),
Preparation of Extractive-Free Wood (D 1105 - 50 T),
Test for Lignin in Wood (D 1106 - 50 T),
Test for Alcohol-Benzene Solubility of Wood (D 1107 - 50 T),
Test for Ether Solubility of Wood (D 1108 - 50 T),
Test for One Per Cent Caustic Soda Solubility of Wood (D 1109 - 50 T), and
Test for Water Solubility of Wood (D 1110 - 50 T).

The recommendations in this report have been submitted to letter ballot of the committee, the results of which will be reported at the Annual Meeting.[5]

ACTIVITIES OF SUBCOMMITTEES

Subcommittee I on Specifications for Timber (Lyman W. Wood, chairman) has been principally engaged during the past year with studies connected with a revision of Tentative Methods for Establishing Structural Grades of Lumber (D 245 - 49 T). A draft of a proposed revision is under consideration and will be further revised during the coming year to accommodate suggestions and comments.

Subcommittee II on Laminated Timber (Frank J. Hanrahan, chairman) has continued its consideration of the revision of the Standard Method of Test for Integrity of Laminated Wood Products for Exterior Service (D 1101) so as to reduce the time required for the test without reducing its effectiveness. It is hoped that more data will become available during the coming year to enable a revision to be completed.

Subcommittee IV on Wood Paving Blocks (W. H. O'Brien, chairman) prepared a revision, as noted earlier in this report, of Standard Specification D 1031 to provide for an alternative class of end-grain wood blocks for interior floors which will admit southern pine blocks having an average of 4 annual rings per inch in addition to the present class based on a requirement of 6 rings per inch.

Subcommittee VI on Timber Preservatives (D. L. Davies, chairman) has a large program of work underway for the coming year.

Subcommittee VII on Wood Poles and Crossarms (R. P. A. Johnson, chairman) has had an active year. Extensive testing work on the ASTM Wood Pole Research Program has been in progress and will continue during the coming year. Progress to date has included completion of the tests of untreated western larch poles in cooperation with the Rocky Mountain Pole and Treating Assn. and work in summarizing the data; the selection and testing of poles of four species of southern pine, of Douglas-fir, and of lodgepole pine; and testing of small clear specimens from the pole material. Analysis of the data is under way. In addition, tests have been completed on the comparison of the machine test method with the crib test method using full-size southern pine poles.

Along with this progress, the Ways and Means Task Group reported on the support of the program by a large number of organizations whose contributions have been most encouraging and enabled the substantial progress to date. The program, however, is not half completed, and the collection of material and testing of treated poles has not been started. It appears that a third year will be required for the work. The committee is inviting further contributions to ensure the completion of the entire program as planned, including tests of treated material.

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[5] The letter ballot vote on these recommendations was favorable; the results of the vote are on record at ASTM Headquarters.

The pole tests have been made in accordance with ASTM Tentative Methods of Static Tests of Wood Poles (D 1036), except for three modifications approved by the Technical Advisory Task Group. These have involved (1) the testing of the poles in the green condition rather than in the butt-soaked condition to afford stability of moisture-strength relationships for comparison between species, for comparison of testing procedures, and for establishing the relationship between the strength of poles and that of small clear specimens taken from the pole material; (2) some modification in method of supporting poles in the machine test and in the method of measuring load; and (3) some modification in the procedure for the crib test method. These proposed revisions have been recommended earlier in this report.

Subcommittee VIII on Modified Wood and Wood-Base Material (W. G. Youngquist, chairman) has received suggestions for changes in the Tentative Specification for Modified Wood (D 1324) and the specification will be reviewed during the coming year.

Subcommittee IX on Methods of Testing (L. J. Markwardt, chairman) has no revisions or actions to recommend at this time. It is of interest to note that some of our standard methods of test are now identical with a number of similar procedures used internationally.

Subcommittee XIII on Durability and Exposure (R. M. Lindgren, chairman) is currently working on the preparation of a tentative aimed at the standardization of the soil-block method for the accelerated testing of wood preservatives and of the natural decay resistance of wood. Factors that are being considered in the study preparatory to standardization are: the kind of weathering to use preceding the test of decay resistance, the selection of a suitable diluent for obtaining different retentions of preservatives, the effect of differences in soil character, the establishment of optimum soil moisture content, and the choice of soil fungi.

Subcommittee XIV on Methods of Chemical Analysis (G. J. Ritter, chairman) has developed a revised method of test for alpha-cellulose in wood which is referred to elsewhere in this report. Also recommended is a slight change in the scope of the Tentative Method of Test for Methoxyl Groups in Wood (D 1166).

Subcommittee XV on Structural Fiberboards (W. C. Lewis, chairman) has recommended several changes in the Methods of Test for Evaluating the Properties of Building Boards (D 1037), as noted elsewhere in this report. The subcommittee has under consideration several additional tests for (*a*) nail head pull through, (*b*) block shear, (*c*) glue line shear, (*d*) falling ball impact. In addition, the subcommittee is now working on a much needed series of standard definitions applicable to fiberboard.

This report has been submitted to letter ballot of the committee, which consists of 92 voting members; 67 members returned their ballots, of whom 61 have voted affirmatively and 0 negatively.

Respectfully submitted on behalf of the committee,

L. J. MARKWARDT,
Chairman.

L. W. SMITH,
Secretary.

REPORT OF COMMITTEE D-8

ON

BITUMINOUS WATERPROOFING AND ROOFING MATERIALS*

Committee D-8 on Bituminous Waterproofing and Roofing Materials held two meetings during the year: one in Chicago, Ill., on June 18, 1954, and the other in Cincinnati, Ohio, on February 1, 1955.

The committee suffered loss through the death of J. J. Paine of the City of Pittsburgh Laboratory, R. J. Potbury of the U. S. Dept. of Navy, Bureau of Yards and Docks, and K. A. Horn of Congoleum-Nairn, Inc.

The committee also suffered loss through the resignation of O. G. Streiter and A. L. Raphael.

The membership, consisting of 76 voting members, is composed of 49 producers, 10 consumers, and 17 general interest.

NEW TENTATIVES

Committee D-8 recommends that the Method of Test for Contact Compatibility of Bituminous Materials published as information with the 1953 Annual Report of the Committee[1] be accepted for publication as tentative, with the following editorial changes:

Title.—Change to read "Oliensis Test for Contact Compatibility Between Asphaltic Materials."

Scope.—Substitute the word "asphaltic" wherever the word "bituminous" appears in the scope.

New Section.—Add the following new section on reproducibility at end of method:

> Incompatibilities of less than 0.2 mm should be reproducible within plus or minus 0.1 mm. Incompatibilities of 0.2 mm to 0.5 mm should be reproducible within 0.2 mm.

REVISION OF TENTATIVE

Committee D-8 recommends that the Tentative Methods of Testing Bituminous Emulsions for Use as Protective Coatings for Metal (**D 1010 - 49 T**)[2] be revised as appended hereto.[3] These methods are under joint jurisdiction with Committee D-1 on Paint, Varnish, Lacquer, and Related Products, and the acceptance of this revision is contingent upon similar action by Committee D-1.

TENTATIVE REVISION OF STANDARDS

Committee D-8 recommends publication of the following tentative revisions of standards:

Standard Specifications for Asphalt Shingles Surfaced with Mineral Granules (D 225 - 54):[4]

Table I.—Change min weight per 100 sq ft, Type III shingles, from "80.0" to read "83.8 lb."

Standard Specifications for Asphalt Roll Roofings Surfaced With Powdered Talc or Mica (D 224 - 54):[4]

Section 10(a).—Delete fourth and sixth sentence referring to end covers.

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* Presented at the Fifty-eighth Annual Meeting of the Society, June 26–July 1, 1955.

[1] *Proceedings*, Am. Soc. Testing Mats., Vol. 53, p. 411 (1953)

[2] 1952 Book of ASTM Standards, Part 3.

[3] The revised tentative appears in the 1955 Book of ASTM Standards, Part 3.

[4] 1954 Supplement to Book of ASTM Standards, Part 3.

Standard Specifications for Asphalt Siding Surfaced with Mineral Granules (D 699 - 54):[4]

Section 10.—Change to read as follows:

> 10. The siding shall be packed in fiberboard wraps or between wood or fiberboard pads and tied securely so as to make a substantial package weighing not more than 135 lb gross.

REVISION OF STANDARD AND REVERSION TO TENTATIVE

Committee D-8 recommends that the Standard Specifications for Wide Selvage Asphalt Roofing Surfaced with Mineral Granules (**D 371 - 51**)[2] be revised as follows and reverted to tentative status:

Delete all reference to 32-in. roofing. Tentative revision issued June, 1953.)

Title.—Change in accordance with tentative revision issued June, 1953,[5] to read: "Specifications for Wide Selvage Asphalt Roll Roofing Surfaced with Mineral Granules."

Table I.—Incorporate tentative revision issued June, 1953.[5]

Section 2.—Change the last sentence to read: "The coated and surfaced portion shall be 17 or 19 in. in width."

Section 6(b).—Change the last sentence to read: "The surfaced portion shall be 17 ± $\frac{1}{4}$ in. or 19 ± $\frac{1}{4}$ in., provided the roofing is marked with a conspicuous mopping line 17 ± $\frac{1}{4}$ in. from the exposed weather edge."

ADOPTION OF TENTATIVE AS STANDARD

The committee recommends that the Tentative Methods of Sampling Bituminous Materials (**D 140 - 52 T**)[2] be approved for reference to letter ballot of the Society for adoption as standard with the following editorial change:

Section 8(a).—In line 3, following the word "secured," add "after thoroughly mixing."

ADOPTION OF TENTATIVE REVISIONS AS STANDARD

Committee D-8 recommends that tentative revisions of the following standards be approved for reference to letter ballot of the Society for adoption as standard:

Standard Methods of Testing Emulsified Asphalts (D 244 - 49):[2] Tentative revision of Sections 2(*b*), 15, and New Section 16 issued September 5, 1952, and editorially modified September, 1954.[4]

Standard Specification for Asphalt Roll Roofing Surfaced with Powdered Talc or Mica (D 224 - 54):[4] Tentative Revision of Section 6(*b*), and Table I, issued June, 1953.[4]

REAPPROVAL OF STANDARDS

Committee D-8 recommends the reapproval of the following standards:

Standard Specifications for:

- Bituminous Grout for Use in Waterproofing above Ground Level (**D 170 - 41**),
- Bituminous Grout for Use in Waterproofing Below Ground Level (**D 171 - 41**),
- Asphalt Mastic for Use in Waterproofing (**D 491 - 41**),
- Woven Cotton Fabrics Saturated with Bituminous Substances for Use in Waterproofing (**D 173 - 44**),
- Asphalt-Saturated Roofing Felt for Use in Waterproofing and in Constructing Built-Up Roof (**D 226 - 47**),
- Coal-Tar Saturated Roofing Felt for Use in Waterproofing and in Constructing Built-Up Roofs (**D 227 - 47**),
- Asphalt-Saturated Asbestos Felts for Use in Waterproofing and in Constructing Built-Up Roofs (**D 250 - 47**),
- Coal-Tar Pitch for Roofing, Dampproofing and Waterproofing (**D 450 - 41**),
- Coal-Tar Pitch for Steep Built-Up Roofs (**D 654 - 49**),
- Asphalt-Saturated and Coated Asbestos Felts for Use in Constructing Built-Up Roofs (**D 655 - 47**),
- Asphalt for Use in Constructing Built-Up Roof Coatings (**D 312 - 44**),
- Asphalt for Dampproofing and Waterproofing (**D 449 - 49**),

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[5] 1953 Supplement to Book of ASTM Standards, Part 3.

Creosote for Priming Coat with Coal-Tar Pitch in Dampproofing and Waterproofing (**D 43 - 41**),
Sieve Analysis of Granular Mineral Surfacing for Asphalt Roofing and Shingles (**D 1001 - 51**), and
Primer for Use With Asphalt in Dampproofing and Waterproofing (**D 41 - 41**), with the following editorial change:

Section 2(a).—Change "Distillation per cent by volume" to read "Distillation per cent by volume of the Primer."

Standard Methods of:

Testing Films Deposited from Bituminous Emulsions (**D 466 - 42**),
Sampling and Testing Felted and Woven Fabrics Saturated with Bituminous Substances for Use in Waterproofing and Roofing (**D 146 - 47**),
Test for Steam Distillation of Bituminous Protective Coatings (**D 255 - 28**),
Tests for Coarse Particles in Mixtures of Asphalt and Mineral Matter (**D 313 - 41**),
Tests for Sieve Analysis of Granular Mineral Surfacing for Asphalt Roofing and Shingles (**D 451 - 40**),
Tests for Sieve Analysis of Nongranular Mineral Surfacing for Asphalt Roofing and Shingles (**D 452 - 40**),
Testing Bituminous Mastics, Grouts and Like Mixtures (**D 147 - 41**) with the following editorial change:

Section 3(b).—Change the first sentence to read: "The apparatus for analysis of samples containing coarse aggregate shall be the large extractor, shown in Fig. 2, consisting of a large heat-resistant glass cylinder for holding the solvent, a cylindrical wire basket made of 80 mesh wire cloth suspended in the cylinder from an inverted conical coil condenser which serves as a top."

Section 5(a).—Change the seventh sentence to read: "The extraction apparatus shall be heated on a steam bath or electric hot plate and the extraction shall be carried on exactly as in the smaller glass extractor, but on a larger scale."

Standard Volume Correction Table for:

Tar and Coal-Tar Pitches (**D 633 - 44**) with the following editorial change:

In the second paragraph, change the heading "Group Number" to read "Group."

Change "OOO" to "A," "OO" to "B" and "O" to "C" as designations for groups in the table in the second paragraph, in the note, and in the corresponding tables of multipliers.

TENTATIVES CONTINUED WITHOUT REVISION

Committee D-8 recommends that the following tentatives be continued without revision, since they are being reviewed for possible revisions:

Tentative Specifications for:

Asphalt-Base Emulsions for Use as Protective Coatings for Built-Up Roofs (**D 1227 - 52 T**),
Asphalt Insulating Siding Surfaced with Mineral Granules (**D 1226 - 52 T**), and
Asphalt Roll Roofings Surfaced with Mineral Granules (**D 249 - 54 T**).

Tentative Methods of Testing:

Asphalt-Base Emulsions for Use as Protective Coatings for Built-Up Roofs (**D 1167 - 51 T**),
Asphalt Insulating Siding Surfaced with Mineral Granules (**D 1228 - 52 T**), and
Asphalt Roll Roofing, Cap Sheets and Shingles (**D 228 - 54 T**).

Tentative Recommended Practice for:

Accelerated Weathering Test of Bituminous Materials (**D 529 - 39 T**).

The recommendations in this report have been submitted to letter ballot of the committee, the results of which will be reported at the Annual Meeting.[6]

This report has been submitted to letter ballot of the committee, which consists of 76 members; 48 members returned their ballots, all of whom have voted affirmatively.

Respectfully submitted on behalf of the committee,

H. R. SNOKE,
Chairman.

G. W. ROBBINS,
Secretary.

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[6] The letter ballot vote on these recommendations was favorable; the results of the vote are on record at ASTM Headquarters.

REPORT OF COMMITTEE D-9

ON

ELECTRICAL INSULATING MATERIALS*

Committee D-9 held three meetings during the year: in Chicago, Ill., on June 14, 15, and 16, 1954, during the Annual Meeting of the Society; in Cleveland, Ohio, on November 17, 18, and 19, 1954; and in Washington, D. C., on March 2, 3, and 4, 1955.

At these meetings, action was taken on new methods, revisions of existing tentatives, and changes in standards under the jurisdiction of the committee. Also, progress was made on other projects under study by the subcommittees as listed later in this report.

At the November meeting in Cleveland, the following officers were elected for the ensuing term of two years:

Chairman, A. H. Scott.
Vice-Chairman, H. K. Graves.
Recording Secretary, J. E. Gibbons.
Membership Secretary, A. J. Balch.

Recommendations Accepted by the Administrative Committee on Standards

Subsequent to the 1954 Annual Meeting, Committee D-9 presented to the Society through the Administrative Committee on Standards the following recommendations:

Tentative Methods of Test for:

Silicone Insulating Varnishes (D 1346 – 54 T).

Revision of Tentative Methods of:

Testing Electrical Insulating Oils (D 117 – 53 T),
Sampling and Testing Untreated Paper Used for Electrical Insulation (D 202 – 53 T),
Testing Vulcanized Fiber Used for Electrical Insulation (D 619 – 52 T),
Testing Nonrigid Polyvinyl Tubing (D 876 – 52 T),
Test for Silicone Insulating Varnishes (D 1346 – 54 T),

Revision of Tentative Specifications for:

Nonrigid Polyvinyl Tubing (D 922 – 52 T),
Absorbent Laminating Paper for Electrical Insulation (D 1080 – 52 T),

Tentative Revision of Standard Methods of:

Testing Laminated Tubes Used for Electrical Insulation (D 348 – 52),
Testing Laminated Round Rods Used for Electrical Insulation (D 349 – 52),
Sampling Electrical Insulating Oil (D 923 – 49), and

Revision and Reversion to Tentative of Standard Specifications for:

Natural Block Mica and Mica Films Suitable for Use in Fixed Mica-Dielectric Capacitors (D 748 – 54).

The new Tentative Methods D 1346, the revision of Tentative Methods D 117, and the recommendation for the revision and reversion to tentative of Standard Specifications D 748 were accepted by the Standards Committee on September 28, 1954; the revision of Tentative Methods D 202 was accepted on February 3, 1955; the remaining recommendations were accepted by the Standards Committee on December 22, 1954. The new and revised tentatives together with the tentative revisions of standards appear in the 1955 Compila-

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*** Presented at the Fifty-eighth Annual Meeting of the Society, June 26–July 1, 1955.**

tion of ASTM Standards on Electrical Insulating Materials.

NEW TENTATIVE

The committee recommends the publication as tentative of the Recommended Practice for Cleaning Plastic Specimens for Insulation Resistance Testing as appended hereto.[1]

REVISION OF TENTATIVES

The committee recommends revisions of the following tentatives as indicated:

Tentative Methods of Testing Askarels (D 901 - 53 T):[2]

Add the test for Volume of Oil in Oil-Contaminated Askarel as appended hereto.[3]

Tentative Methods of Testing Varnished Cloths and Varnished Cloth Tapes Used for Electrical Insulation (D 295 - 54 T):[4]

Revise as appended hereto.[3]

Tentative Methods of Testing Pressure-Sensitive Adhesive Tapes Used for Electrical Insulation (D 1000 - 53 T):[2]

Revise as appended hereto.[3]

Tentative Specifications for Phenolic Molding Compounds (D 700 - 54 T)[4] (jointly with Committee D-20 on Plastics):

Section 2.—Add the following types:

Type 14.—General purpose wood-flour filled rubber-modified phenolplastic.

Type 15.—General purpose rubber-modified phenolplastic with a cellulose filler which may be wood-flour or cotton flock.

Type 16.—Moderate impact strength rubber-modified phenol-plastic with chopped cotton fabrics or other suitable forms of cellulose filler to give the required strength for this type.

Type 17.—Medium impact strength rubber-modified phenol-plastic with chopped cotton fabrics or other suitable forms of cellulose filler to give the required strength for this type.

Type 18.—Heat-resistant mineral-filled rubber-modified phenolplastic.

Section 3(b).—Add the values given below to the table in the Note:

Type	Particle Size, U. S. Standard Sieve No.	Pourability,[a] max, sec.	Apparent Density, min, g per cu cm	Bulk Factor,[a] max
14	10	30	0.40	3.5
15	10	...	0.40	3.5
16	...	...	0.30	4.0
17	...	...	0.15	8.0
18	10	25	0.60	2.5

Table I.—Add the requirements for grades 14 to 18 as listed in the accompanying Table I.

Tentative Specifications for Laminated Thermosetting Materials (D 709 - 54 T):[4]

This specification is under joint jurisdiction with Committee D-20 on Plastics, and the proposed revision appears on p. 559 of the Report of Committee D-20.

Tentatve Test for Saponification Number of Petroleum Products by Color-Indicator Titration (D 94 - 52 T):

This test is under joint jurisdiction with Committee D-2 on Petroleum Products and Lubricants, and the proposed revision appears on p. 449 of the Report of Committee D-2.

MODIFICATION OF TENTATIVE REVISION OF STANDARD

The committee recommends the following modification of a tentative revision[4] of the Standard Methods of Testing Flexible Varnished Tubing Used for Electrical Insulation (**D 350 - 48**):[5]

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[1] The new tentative appears in the 1955 Book of ASTM Standards, Part 6.

[2] 1953 Supplement to Book of ASTM Standards, Part 6.

[3] The revised tentative appears in the 1955 Book of ASTM Standards, Part 6.

[4] 1954 Supplement to Book of ASTM Standards, Part 6.

[5] 1952 Book of ASTM Standards, Part 6.

TABLE I.—DETAIL REQUIREMENTS FOR MOLDED TEST SPECIMENS.
(Addition to Table I, D 700.)

	Type 14	Type 15	Type 16	Type 17	Type 18
Water absorption, max, weight gain, per cent	1.5	1.5	1.5	1.5	0.3
Specific gravity, 23/23 C (73.4/73.4 F) max	1.35	1.35	1.35	1.35	1.70
Flexural strength, min, psi	7 000	7 000	7 000	7 000	6 000
Impact strength, (Izod), min, ft-lb per in. of notch	0.35	0.45	0.80	2.00	0.30
Tensile strength (⅛ in. specimen), min, psi	3 500	4 000	4 000	4 000	4 000
Compressive strength, min, psi	15 000	15 000	15 000	15 000	15 000
Modulus in flexure max, psi	4×10^5	4×10^5	5×10^5	5×10^5	8×10^5
Mold shrinkage in. per in.:					
Min.	0.005	0.004	0.004	0.002	0.004
Max.	0.010	0.009	0.008	0.006	0.008
Insulation resistance min, megohms	100	100	100	100	100
Dielectric strength, min v per mil:					
Short-time Test	275	300	275	250	275
Step-by-step Test	225	275	225	200	225

Section 14(a).—Change the first table to read as follows:

Class AA-1, AA-2, AB-1, AB-2	105 $\pm^{5}_{0}$C (221 $\pm^{9}_{0}$F)
Class BA-1, BA-2, BB-1, BB-2	130 $\pm^{5}_{0}$C (266 $\pm^{9}_{0}$F)
Class HA-1, HA-2	200 $\pm^{5}_{0}$C (392 $\pm^{9}_{0}$F)

REVISION OF STANDARD AND REVERSION TO TENTATIVE

The committee recommends that the Standard Method of Test for Dielectric Breakdown Voltage and Dielectric Strength of Electrical Insulating Materials at Commercial Power Frequencies (**D 149 - 44**)[5] be revised as appended hereto and reverted to tentative status.[3]

The committee also recommends that the Standard Methods of Testing Pasted Mica Used in Electrical Insulation (**D 352 - 52 T**)[5] be revised as appended hereto and reverted to tentative status,[3] subject to confirming letter ballot of Committee D-9 now in progress.

ADOPTION OF TENTATIVES AS STANDARD WITHOUT REVISION

The committee recommends that the following tentatives be approved for reference to letter ballot of the Society for adoption as standard without change:

Tentative Specification for:

Black Bias-Cut Varnished Cloth and Varnished Cloth Tape Used for Electrical Insulation (**D 373 - 51 T**),[5] and

Tentative Method of Testing:

Varnishes Used for Electrical Insulation (**D 115 - 52a T**).[5]

EDITORIAL CHANGES

The committee recommends editorial changes in the following standards as indicated:

Tentative Specifications for Orange Shellac and Other Indian Lacs for Electrical Insulation (D 784 - 52 T):[5]

Section 2.—In the first sentence of the Note, delete the words "commonly known by these ASTM designations[3]," which also involves the deletion of Footnote 3.

Standard Method for Sampling Electrical Insulating Oils (D 923 - 49):[5]

Section 3(a).—Following the third sentence, add "It is desirable that sampling valves should be so located as to insure obtaining a sample from the extreme lowest point of the apparatus tank."

MODIFICATIONS IN COMMITTEE D-9 COMPILATION

The committee recommends that Appendix I, Significance of Tests of Electrical Insulating Materials, be deleted from the Committee D-9 compilation of Specifications and Methods of Testing.

The recommendations in this report have been submitted to letter ballot of the committee, the results of which will be reported at the Annual Meeting.[6]

ACTIVITIES OF SUBCOMMITTEES

Subcommittee I on Insulating Varnishes, Paints, and Lacquers (A. H. Haroldson, chairman) developed the Tentative Methods of Test for Silicone Varnishes (D 1346 - 54 T) which were recently approved by the Administrative Committee on Standards.

The subject of viscosity measurements is being brought to the attention of Committee E-1 on Methods of Testing in order that a committee may be formed for developing and standardizing viscosity measuring methods. A recent survey by Section J on Physical Properties showed that 21 companies use 18 different methods of measuring viscosity of varnishes.

Section K on Definition and Significance of Tests has been disbanded and its work transferred to Subcommittee XI on Significance of Tests. Section chairmen will prepare significance statements for the use of Subcommittee XI.

Subcommittee III on Plates, Tubes, Rods, and Molded Materials (E. A. Russell, chairman) prepared the new Tentative Recommended Practice for Cleaning Specimens for Insulation Resistance Testing referred to earlier in the report, as well as the revision of Tentative Specifications D 700 - 54 T and D 709 - 54 T.

Section F on Conditioning was discontinued and its work transferred to Subcommittee XIV on Conditioning. Section T on Significance of Tests was discontinued and its work transferred to Subcommittee XI on Significance of Tests.

Among the many other subcommittee activities in progress, only a small part can be mentioned here. Currently of most interest for consideration as an ASTM standard is the NEMA Standard for Copper-Clad XXXP Laminate. A current project with Committee D-20 on Plastics is the consolidation of Standard Method of Measuring Shrinkage from Mold Dimensions of Molded Materials Used for Electrical Insulation (D 551 - 41) with Standard Method of Measuring Shrinkage from Mold Dimensions of Molded Plastics (D 955 - 51).

Subcommittee IV on Liquid Insulation (F. M. Clark, chairman) prepared the Test for Volume of Oil in Oil-Contaminated Askarels which is to be substituted for Sections 46 to 50 of Tentative Methods of Testing Askarels (D 901 - 53 T), as referred to earlier in the report.

During the year the subcommittee has been active in the following fields of insulation oil study: neutralization value, sludge tests, metal content, saponification number, sampling, cable impregnants, emulsion tests, transformer oil additives, power factor tests, gas content, viscosity, dielectric strength of viscous oils, water content, peroxides, sulfur corrosion, interfacial tension, specific optical dispersion, and gas evolution under voltage stress. Study has also been given to testing of askarels and to statistical analysis of test data.

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[6] The letter ballot vote on these recommendations was favorable; the results of the vote are on record at ASTM Headquarters.

Subcommittee IV sponsored a symposium at the meeting of Committee D-9 in November, 1954, on "European Development in the Testing of Transformer Oils." Three papers were presented, representative respectively of methods in use in Great Britain, France, and Sweden. The papers and discussion are now being prepared for publication.[7]

Subcommittee VI on Solid Filling and Treating Compounds (W. R. Dohan, chairman).—Major work of the subcommittee has been on a proposed revision of the Standard Methods of Testing Solid Filling and Treating Compounds (D 176 - 44). A draft of revised electrical tests has been prepared by Section A on Electrical Tests and submitted to subcommittee letter ballot. Scope and significance statements have been reviewed and submitted to subcommittee letter ballot.

Subcommittee VII on Insulating Fabrics (H. K. Graves, chairman) completed extensive revisions of the Tentative Methods of Testing Varnished Cloths and Varnished Cloth Tapes (D 295 - 54 T), and the Tentative Methods of Testing Pressure-Sensitive Adhesive Tapes (D 1000 - 53 T) referred to earlier in the report.

The purpose of the revision of the Standard Methods of Testing Flexible Varnished Tubing Used for Electrical Insulation (D 350 - 48), referred to previously, is to clarify classification of tubing with respect to aging temperature.

Subcommittee work in progress comprises revisions of the Tentative Specifications for Flexible Treated Cotton and Rayon Sleeving Used in Electrical Insulation (D 372 - 47 T), and of the Tentative Methods of Testing Varnished Glass Fabrics and Varnished Glass Fabric Tapes Used for Electrical Insulation (D 902 - 52 T).

Other activity of the subcommittee is on methods of testing vinyl-glass sleeving, silicone-rubber and glass-fiber insulation, and tetrafluoroethylene and glass-fiber insulation. A specification has been written for silicone-varnished glass-fiber insulation.

Subcommittee VIII on Insulating Papers (H. A. Anderson, chairman) has sponsored the revisions of Tentative Methods of Sampling and Testing Untreated Paper Used for Electrical Insulation (D 202 - 53 T) and Tentative Specification for Absorbent Laminating Paper Used for Electrical Insulation (D 1080 - 54 T), recently approved by the Administrative Committee on Standards.

Other work of the subcommittee has been on a method of test for power factor of dry paper, on measurement of air resistance in terms of porosity of paper, on a draft of a specification for capacitor tissue, on determination of soluble chloride content of paper, and on means of measuring "paper to paper" friction.

Subcommittee IX on Mica Products (K. G. Coutlee, chairman) has considered the advisability of commingling (blending) specimens of block mica of different grades when assembling standard samples as defined in the Tentative Specifications for Natural Muscovite Mica Based on Visual Quality (D 351 - 53 T).

Subcommittee XI on Significance of Tests (C. L. Craig, chairman) has been reorganized since September, 1954, after a period of inactivity. Future plans include a listing of "Definitions of Electrical Insulation Terms," a review of all scope statements, and sponsorship of a symposium on minimum values.

Subcommittee XII on Electrical Tests (G. M. L. Sommerman, chairman).—An extensive revision was completed of the Standard Methods of Test for Dielectric Strength of Electrical Insulating Materials at Commercial Power

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[7] Issued as separate publication *ASTM STP No. 172.*

Frequencies (D 149 - 44) as mentioned earlier in this report.

During the year the subcommittee sponsored two symposia, one on Thermal Capability of Materials[8] and another on Electrode Techniques. Additional symposia are planned on Corona Resistance of Materials and Related Measurements, and on Thermal Stability of Materials.

The subcommittee is active in studies of: resistivity of solids, particularly as affected by dielectric absorption at constant voltage; dielectric loss of quartz plates at radio frequencies; dielectric strength, as exemplified by the revision of Method D 149; arc resistance, looking toward extension of present low-current procedures (Method D 495 - 48 T) to high-current conditions; guiding principles for applying electrodes in dielectric strength tests; thermal capability of materials; and corona resistance of materials.

Subcommittee XIV on Conditioning (G. H. Mains, chairman) has proposed, but not yet completed, a revision of Standard Methods of Conditioning Plastics and Electrical Insulating Materials for Testing (D 618 - 54). The revision will add three temperatures to the list of standard temperatures, corresponding to limit temperatures of new AIEE insulation classes, and will provide some editorial changes.

Also proposed for letter ballot of the subcommittee is a revision of the Tentative Specification for Enclosures and Servicing Units for Tests Above and Below Room Temperature (D 1197 - 54 T).

A symposium is planned on "Experience in Conditioning Large Laboratory Spaces to ASTM Standard Test Conditions."

Special Subcommittee on Technical Papers (L. B. Schofield, chairman) has had an active year. As noted under activities of Subcommittees IV and XII, symposia were held during the year on European methods of testing insulating oils, thermal capability of materials, and electrode techniques. Other symposia are planned on methods for obtaining minimum strength values of materials, sponsored by Subcommittee XI; on corona resistance of materials, and a further discussion on high-temperature performance and capabilities of electrical insulation, both sponsored by Subcommittee XII; and on tests on electrical insulating oils, sponsored by Subcommittee IV.

This report has been submitted to letter ballot of the committee, which consists of 190 members; 103 members returned their ballots, of whom 95 have voted affirmatively and 0 negatively.

Respectfully submitted on behalf of the committee,

A. H. SCOTT,
Chairman.

J. E. GIBBONS,
Recording Secretary.

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[8] Available as *ASTM STP No. 161*, "Temperature Stability of Electrical Insulating Materials."

EDITORIAL NOTE

Subsequent to the Annual Meeting, Committee D-9 presented to the Society through the Administrative Committee on Standards the recommendation that the Standard Methods of Testing Pasted Mica Used in Electrical Insulation (D 352 - 52) be revised and reverted to tentative status. This recommendation was accepted by the Standards Committee on September 15, 1955, and the revised methods appear in the 1955 Book of ASTM Standards, Part 6.

REPORT OF COMMITTEE D-10
ON
SHIPPING CONTAINERS*

Committee D-10 on Shipping Containers held two meetings during the year: at Chicago, Ill., on October 1, 1954, and at the Forest Products Laboratory at Madison, Wis., on April 22, 1955.

New Tentative

Committee D-10 recommends that the Methods of Testing Package Cushioning Materials be accepted for publication as tentative as appended hereto.[1] The method is intended to measure load-displacement, thickness loss, drift, and permanent set of bulk, sheet, or molded forms used for compressible cushioning materials.

Tentatives Continued Without Revision

The committee recommends that the following tentatives, which have stood without revision for two or more years, be continued as tentative:

Tentative Methods of:

Test for Water Vapor Permeability of Packages by Cycle Method (**D 1251 - 53 T**),
Test for Water Vapor Permeability of Shipping Containers by Cycle Method (**D 1276 - 53 T**),
Testing Pallets (**D 1185 - 51 T**), and
Vibration Test for Shipping Containers (**D 999 - 48 T**).

Methods D 1251, D 1276, and D 1185 are being continued as tentative since there has been no indication of sufficient field application to establish their adequacy. A special task group has not as yet completed its extensive review and revision of Method D 999.

The recommendations in this report have been submitted to letter ballot of the committee, the results of which will be reported at the Annual Meeting.[2]

Activities of Subcommittees

Subcommittee I on Definitions of Terms (E. J. Dahill, chairman) has completed its revision of the Standard Definitions of Terms Relating to Shipping Containers (D 996 - 50), which will be submitted for letter ballot by the entire committee at an early date.

Subcommittee II on Methods of Testing (J. G. Turk, chairman),

Subcommittee IV on Performance Standards (C. R. Gustafson, chairman),

Subcommittee V on Correlation of Tests (R. C. McKee, chairman):

These three subcommittees continued to function as a joint committee consisting of four task groups, each of which is conducting an extensive review and investigation of separate test procedures which, though well-established, were found to yield data of poor reproducibility.

The Task Group on Revolving Drum Test has found wide variations in dimensions of existing 7-ft drums.

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* Presented at the Fifty-eighth Annual Meeting of the Society, June 26-July 1, 1955.

[1] The new tentative appears in the 1955 Book of ASTM Standards, Part 7.

[2] The letter ballot vote on these recommendations was favorable; the results of the vote are on record at ASTM Headquarters.

Present drawings will be revised to emphasize the exact positioning of hazards with reference to the center lines of faces, thus minimizing the cumulative effect of tolerances. Factors other than dimensional differences will also receive further study.

The Task Group on Vibration Test has completed preliminary test work which has provided basic data required for setting up a more elaborate program designed to study the effect of weight and location of load at several frequencies.

The Task Group on Drop Test has been successful in reaching certain conclusions with reference to the effect of dropping surface in relation to the weight of object dropped, and to the effect of package orientation prior to drop. A revision of the present method will be prepared for comment by the membership of Committee D-10.

The Task Group on Stacking completed a collaborative test which resulted in widely variant data. The test procedure has been modified and a second round robin is under way.

Subcommittee III on Water Vapor Resistance (H. A. Bergstrom, chairman) completed a collaborative test in accordance with Method of Test for Water Vapor Permeability of Shipping Containers (D 1008 - 51). The data revealed several conditions which will have to be more rigidly specified, and a second collaborative test designed to check such conclusions is nearly completed. Further study should result in a revised method capable of satisfactory reproducibility of test results.

Subcommittee VI on Interior Packing (S. L. Swenson, chairman) prepared the Methods of Testing Package Cushioning Materials referred to earlier in the report. The subcommittee's work on a bibliography of cushioning studies has been actively pursued. Task groups were appointed to explore the development of a test method for dynamic load deflection properties of cushioning materials, the development of cushion tests for nonresilient packing components, and the development of test methods for characteristics of cushioning materials other than load deflection.

This report has been submitted to letter ballot of the committee, which consists of 101 voting members; 67 members returned their ballots, of whom 62 have voted affirmatively and 0 negatively.

Respectfully submitted on behalf of the committee,

G. E. FALKENAU,
Chairman.

R. F. UNCLES,
Secretary.

REPORT OF COMMITTEE D-11

ON

RUBBER AND RUBBER-LIKE MATERIALS*

Committee D-11 on Rubber and Rubber-Like Materials and seventeen of its subcommittees held meetings in Cincinnati, Ohio, on February 2 to 4, 1955, during ASTM Committee Week. At the February, 1955, meeting, the following two papers were presented:

S. A. Eller, "Stress Relaxation of Vulcanized Rubber in Compression and Tension," ASTM BULLETIN, No. 207, July, 1955, p. 78 (TP150).

D. R. Lem and J. M. Reynar, "Stress Relaxation of Nonmetallic Gasket Materials," ASTM BULLETIN, No. 207, July, 1955, p. 81 (TP153).

In addition, some of the subcommittees have held separate meetings during the year; and the SAE-ASTM Technical Committee on Automotive Rubber, with its various sections, has met on a quarterly basis.

The committee has formulated plans and is currently proceeding to extend its activities into the important field of development of voluntary standards for synthetic rubbers and latices. Standardization in connection with the manufacture and testing of these materials has been an essential part of the government synthetic rubber program and has been carried on under the jurisdiction of the Office of Synthetic Rubber of the Reconstruction Finance Corporation since the original establishment of the government synthetic rubber facilities during World War II. Following the decision this past year by the government to dispose of these facilities to private industry, it became evident that future standardization activities would necessarily be the responsibility of the purchasers of the government plants and those concerned with the commercial use of their production. Committee D-11 offered its services in this connection and at the request of a group of the plant operators a new Subcommittee XIII on Synthetic Elastomers has been organized under the chairmanship of B. S. Garvey, Jr., to carry on this work. This subcommittee, which consists of representatives of the synthetic rubber manufacturers together with users and general interest members, has already started work on six of the present government test methods looking toward having them published as ASTM Methods. The scope of activities of the subcommittee has been defined as "the development and standardization of test methods, nomenclature, and specifications relating to synthetic elastomers and their latices," but work will necessarily be limited for the present to test methods for the most generally used types of synthetics which are currently being produced. The subcommittee is establishing six working sections as follows: Sampling, chemical tests for solid polymers, physical tests for solid polymers, latex test methods, nomenclature, and standard reference materials. It is hoped within the next few months to have some of the test methods available in tentative form for presentation to the Society through the Administrative Committee on Standards.

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* Presented at the Fifty-eighth Annual Meeting of the Society, June 26–July 1, 1955.

RECOMMENDATIONS ACCEPTED BY THE ADMINISTRATIVE COMMITTEE ON STANDARDS

The following recommendations presented to the Society through the Administrative Committee on Standards were accepted on January 10, 1955:

Tentative Specification for:

- Construction of Rubber Insulated Wire and Cable (D 1350 - 54 T),
- Polyethylene Insulated Wire and Cable (D 1351 - 54 T), and
- Ozone-Resisting Butyl Rubber Insulation for Wire and Cable (D 1352 - 54 T).

Tentative Recommended Practice for:

- Standard Test Temperatures for Rubber and Rubber-Like Materials (D 1349 - 54 T).

Revision of Tentative Specification for:

- Natural Rubber AO Insulation for Wire and Cable (D 27 - 54 T),
- Natural Rubber Performance Insulation for Wire and Cable (D 353 - 54 T),
- Natural Rubber Heat-Resisting Insulation for Wire and Cable (D 469 - 54 T),
- Ozone-Resisting Insulation for Wire and Cable (D 574 - 54 T),
- Heavy Duty Neoprene Sheath for Wire and Cable (D 752 - 54 T),
- Synthetic Rubber Heat-Resisting Insulation for Wire and Cable (D 754 - 54 T),
- Synthetic Rubber Performance Insulation for Wire and Cable (D 755 - 54 T),
- GR-S Synthetic Rubber Sheath for Wire and Cable (D 866 - 54 T), and
- Non-Metallic Gasket Materials for General Automotive and Aeronautical Purposes (D 1170 - 54 T).

Revision of Tentative Methods of:

- Testing Rubber and Thermoplastic Insulated Wire and Cable (D 470 - 54 T),
- Chemical Analysis of Rubber Products (D 297 - 54 T),
- Test for Change in Properties of Elastomeric Vulcanizates Resulting from Immersion in Liquids (D 471 - 54 T),
- Test for Low Temperature Brittleness of Rubber and Rubber-Like Materials (D 736 - 54 T), and
- Heat Aging of Vulcanized Natural or Synthetic Rubber by Test Tube Method (D 865 - 54 T).

Revision of Tentative Specifications and Methods of Test for:

- Concentrated, Ammonia Preserved, Creamed and Centrifuged Natural Rubber Latex (D 1076 - 54 T).

Revision and Reversion to Tentative of Standard Specifications for:

- Natural Rubber Sheath for Wire and Cable (D 532 - 54 T), and
- Light Duty Neoprene Sheath for Wire and Cable (D 753 - 54 T).

The new and revised tentatives appear in the 1954 Supplement to Book of ASTM Standards, Part 6, and in the Compilation of ASTM Standards on Rubber and Rubber-like Materials, bearing the designations indicated above.

The Tentative Specifications for Polyethylene Insulated Wire and Cable (D 1351) and for Ozone-Resisting Butyl Rubber Insulation (D 1352) provide standards for two of the newer types of insulation which have come into wide use in recent years. These were much needed in the industry. The acceptance of the Tentative Specifications for Construction of Rubber Insulated Wire and Cable (D 1350), combined with the revision of the test methods (D 470), and revisions of ten of the specifications covering insulation and sheath compounds, completes a program of three years' work by Subcommittee V on Insulated Wire and Cable intended to make these standards cover the best modern practices and to present them in the most convenient usable form.

The new Tentative Recommended Practice for Standard Test Temperatures for Rubber and Rubber-Like Materials (D 1349) is expected to promote standardization by eliminating specification requirements involving minor temperature differences. This will reduce in many cases the amount of laboratory equipment needed and will facilitate comparisons of test results.

The revision of the Tentative Specifications for Automotive Gasket Materials (D 1170) adds four grades of compositions of natural and/or synthetic rubber and fiber in Table I, Type 1 covering rubber gaskets and three grades of natural and/or synthetic rubber impregnated fibers in Table III, Type 3 covering treated and untreated paper gaskets. These additions were recommended by the SAE-ASTM Technical Committee on Automotive Rubber and are grades of gasketing now in commercial use.

In the revision of the Tentative Methods for Chemical Analysis of Rubber Products (D 297), some rearrangement, clarification, and improvements, which have been found desirable, have been made in the new methods for determining copper and manganese which were adopted earlier in the year.

The revision of the Tentative Methods of Test for Change in Properties of Elastometric Vulcanizates Resulting from Immersion in Liquids (D 471) is the result of an extensive review of the methods by Subcommittee XIX. The methods have been rewritten to eliminate unnecessary wording and sections no longer in use as well as to incorporate suggested improvements. The change in the Tentative Method of Test for Low-Temperature Brittleness (D 736) consisted of the elimination of the 96-hr exposure period formerly specified for natural rubber compounds and the standardization on a 5-hr exposure period for both natural and synthetic rubber compounds. The 96-hr period is considered unnecessarily time-consuming for the purposes for which the test is used. The revision of the Tentative Method of Heat Aging by the Test Tube Method (D 865) provides for the use of metal block heaters as well as oil or water baths since these are finding wide use because of their accuracy, convenience, and safety. In the revision of the Tentative Specifications and Methods of Test for Concentrated, Ammonia Preserved, Creamed and Centrifuged Natural Rubber Latex (D 1076), the former provisional requirement for mechanical stability of 400 sec min is changed to a minimum of 475 sec on a permanent instead of provisional basis. Also the former methods of analysis for copper and manganese are replaced by the new methods specified in the 1954 revision of Methods D 297.

NEW TENTATIVE

Committee D-11 recommends for publication as tentative the Specifications for Ozone-Resistant Rubber Insulating Tape as appended hereto.[1] These specifications cover a type of tape now commercially available and in wide use. The specifications are the result of several years of study by Subcommittee IX on Insulating Tape and are expected to fill a real need in the electrical industry.

REVISIONS OF TENTATIVE

The committee recommends that the following six tentatives be revised as indicated and continued as tentative:

Tentative Methods of Sample Preparation for Physical Testing of Rubber Products (D 15 - 54 T):[2]

Section 13(b).—Add the following as the third sentence of this section:

"An alternate type of test slab mold made by the cut-off bar method with a lower plate thickness of $\frac{3}{4}$ in. is shown in Fig. 2."

Figure 2.—Add a new Fig. 2 as shown in the accompanying Fig. 1.

Tentative Methods of Test for Adhesion of Vulcanized Rubber to Metal (D 429 - 47 T):[3]

This revision, appended hereto,[4] replaces the present Method B covering the adhesion testing of rubber parts assembled to one metal plate, Sections 11 to 17, inclusive, with a new revised method which has been under study for several years in Subcommittee XX on Adhesion Tests. The new method has been evaluated by extensive round-robin testing and statistical analysis of the results and has been shown to be superior to the present method.

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[1] The new tentative appears in the 1955 Book of ASTM Standards, Part 6.

[2] 1954 Supplement to Book of ASTM Standards, Part 6.

[3] 1952 Book of ASTM Standards, Part 6.

[4] The revised tentative appears in the 1955 Book of ASTM Standards, Part 6.

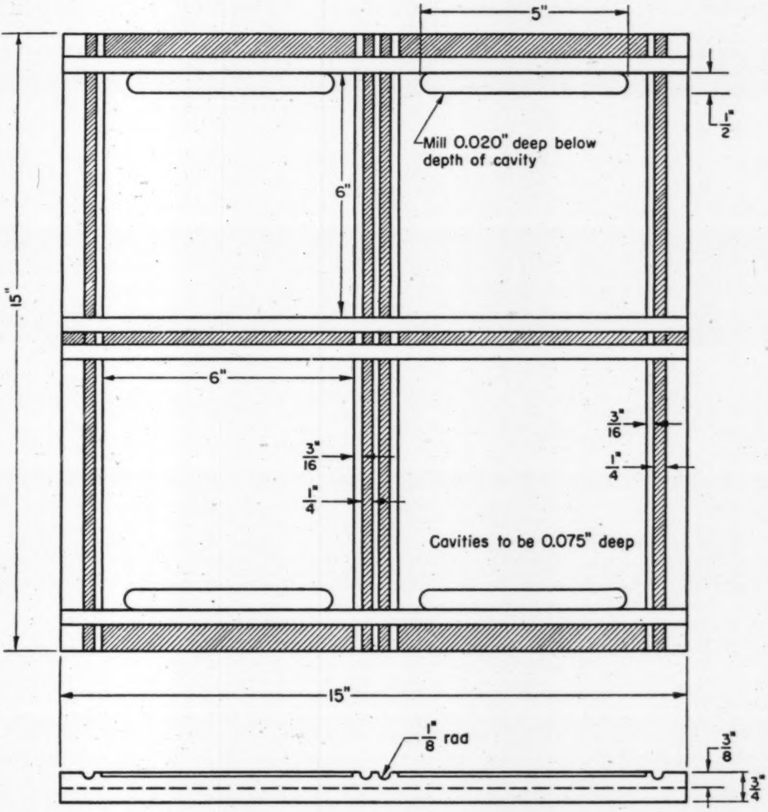
5"
Mill 0.020" deep below depth of cavity
6"
15"
1/2"
6"
3/16"
1/4"
3/16"
1/4"
Cavities to be 0.075" deep
15"
1/8" rad
3/8"
3/4"

FIG. 1.—Cut-off Bar Type of Test Slab Mold.

Tentative Methods of Test for Change in Properties of Elastomeric Vulcanizates Resulting from Immersion in Liquids (D 471 – 54 T):[2]

Section 3(a).—Change the recommended test temperatures to read as follows to bring them into conformity with the Recommended Practice for Standard Test Temperatures (D 1349):

Fahrenheit Temperature	Centigrade Temperature
73.4 ± 2	23 ±1.1
158 ± 1.8	70 ±1
212 ± 1.8	100 ±1
257 ± 1.8	125 ±1
302 ± 1.8	150 ±1
347 ± 1.8	175 ±1
392 ± 1.8	200 ±1
482 ± 1.8	250 ±1

Section 3(b).—Change the 30-day immersion period to read "28 days" for greater convenience in the laboratory scheduling of tests.

Section 9.—Add the following to the end of Note 5:

If, in the course of determining the immersed weight, the test specimen floats, use AISI No. 316 stainless steel as ballast. This ballast material shall be used to immerse the test specimen in the test fluid.

Tentative Methods of Testing Hard Rubber Products (D 530 - 50 T):[3]

New Sections.—Under Impact Resistance, add new Sections 40 to 45 as appended hereto, covering the drop-ball method, and make the additional changes there indicated.[4]

Tentative Methods of Testing Automotive Air Brake and Vacuum Brake Hose (D 622 - 54 T):[2]

New Section.—Under Air Brake Hose add a new Section 11 as follows and renumber the subsequent sections accordingly:

11. *Length Change.*—The hose shall be laid out in a straight, horizontal position and a pressure of 10 psi applied. The original length shall be measured at this pressure. The pressure shall then be increased to 200 psi without releasing the original pressure of 10 psi and a final length measurement made within 1 min. An increase in the final length from the original length shall be reported as elongation. A decrease in the final length from the original length shall be reported as contraction.

This new section is made necessary by changes in test requirements of SAE specifications for air brake hose covering hose which is built on mandrels and that which is nonmandrel built.

Tentative Method of Test for Resistance to Accelerated Light Aging of Rubber Compounds (D 750 - 43 T):[3]

Section 3(e).—Change to read as follows:

(*e*) *Temperature.*—The temperature within the apparatus shall be controlled by the circulation of sufficient air to produce a black panel temperature of 145 ± 5 F when measured by a standard black-painted panel with a suitable thermometer or thermocouple imbedded in the surface. The panel temperatures shall be taken in a position where the water spray is not striking the panel and at the point where maximum heat is developed due to light exposure.

NOTE.—Although a black panel temperature of 63 ± 2.8 C (145 ± 5 F) is specified as standard, it is permissible to use other temperatures if 63 C (145 F) is found unsuitable for the product being tested. In such cases, the temperature actually used shall be reported.

Section 7(a).—Delete the third sentence specifying air temperature between 35 and 45 C surrounding the specimen.

These changes bring the method into conformity with the recommended practice for testing paint films using the same apparatus as specified in ASTM Method D 822 - 46 T.

ADOPTION OF TENTATIVES AS STANDARD WITHOUT REVISION

The committee recommends that the following 13 tentatives be approved for reference to letter ballot of the Society for adoption as standard without revision:

Tentative Recommended Practice for:

Classifying Elastomeric Compounds for Resilient Automotive Mountings (**D 1207 - 52 T**),[3]

Tentative Methods of:

Testing Hydraulic Brake Hose (**D 571 - 52 T**),[3]
Test for Compression Set of Vulcanized Rubber (**D 395 - 53 T**),[5]
Test for Physical State of Cure of Vulcanized Rubber (T-50 Test) (**D 599 - 40 T**),[3]
Test for Permeability of Vulcanized Rubber or Synthetic Elastomers to Volatile Liquids (**D 814 - 46 T**),[3]
Testing Rubber Cements (**D 816 - 51 T**),[3]
Test for Contact and Migration Stain of Vulcanized Rubber in Contact with Organic Finishes (**D 925 - 51 T**),[3]
Test for Mechanical Properties of Elastomeric Vulcanizates Under Compressive or Shear Strains by the Mechanical Oscillograph (**D 945 - 52 T**),[3]
Test for Resistance of Vulcanized Rubber or Synthetic Elastomers to Cut Growth by the Use of the Ross Flexing Machine (**D 1052 - 52 T**),[3]

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[5] 1953 Supplement to Book of ASTM Standards, Part 6.

Test for Impact Resilience and Penetration of Rubber by the Rebound Pendulum (**D 1054 - 53 T**),[5]

Test for Discoloration of Vulcanized Rubber: Organic Finish Coated or Light Colored (**D 1148 - 51 T**),[3]

Test for Weather Resistance Exposure of Automotive Rubber Compounds (**D 1171 - 51 T**),[3] and

Test for Low-Temperature Compression Set of Vulcanized Elastomers (**D 1229 - 52 T**).[3]

All of these tentatives have been published for several years and are in regular use. No criticisms or suggestions for improvement of the methods have been received by the committee.

TENTATIVES CONTINUED WITHOUT REVISION

The committee recommends that all tentatives under its jurisdiction, other than those mentioned in this report, be continued as tentative. Most of these are being revised by the various subcommittees, and the results of this work will be presented to the Society as it is completed.

REAPPROVAL OF STANDARDS

The committee recommends that the following ten standards under its jurisdiction which have stood for six years or more without revision be continued in their present form:

Standard Specifications for:

Rubber Matting for Use Around Electric Apparatus (Voltage Rating of Matting, 3000 volts) (D 178 - 24),

Cotton Rubber-Lined Fire Hose for Public and Private Fire Department Use (D 296 - 49),

Standard Methods of Test for:

Abrasion Resistance of Rubber Compounds (D 394 - 47),

Adhesion of Vulcanized Rubber (D 413 - 39),

Test for Resistance to Light Checking and Cracking of Rubber Compounds (D 518 - 44),

Indentation of Rubber by Means of the Pusey and Jones Plastometer (D 531 - 49),

Viscosity and Total Solids Content of Rubber Cements (D 553 - 42),

Compression-Deflection Characteristics of Vulcanized Rubber (D 575 - 46),

Young's Modulus in Flexure of Natural and Synthetic Elastomers at Normal and Subnormal Temperatures (D 797 - 46), and

Hydrogen Permeability of Rubber-Coated Fabrics (D 815 - 47).

These are believed to be in accord with present practice although possible revision is under consideration in the Standard Specifications D 296 - 49 and in Standard Methods D 394 - 47. When completed, the changes will be presented to the Society as tentative revisions of the standards.

The recommendations in this report have been submitted to letter ballot of the committee, the results of which will be reported at the Annual Meeting.[6]

ACTIVITIES OF SUBCOMMITTEES

Appointment of C. P. Mullen, The Gates Rubber Co., as chairman of Subcommittee I on Mechanical Rubber Hose has been announced, replacing A. E. Williams who resigned. Also, J. D. Heide has resigned as chairman of Subcommittee XXVIII on Statistical Quality Control and has been succeeded by E. M. Bader, The B. F. Goodrich Co.

The various subcommittees of Committee D-11 are engaged in so many interesting projects that only a few which seem to be nearing the final stages can be mentioned here.

Subcommittee IV on Protective Equipment for Electrical Workers (Gordon Thompson, chairman) has under consideration a proposed revision of the Tentative Specifications for Rubber Insulating Sleeves (D 1051 - 49 T) which has been prepared by one of its sections. It is hoped that this revision can be presented to the Society through the

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[6] The letter ballot vote on these recommendations was favorable; the results of the vote are on record at ASTM Headquarters.

Administrative Committee on Standards later this year.

Subcommittee VI on Packings (F. C. Thorn, chairman) is balloting on proposed tentative specifications for a second grade red sheet packing which, if approved, will be presented to the Society for publication in conjunction with the present Tentative Specifications for Sheet Rubber Packing (D 1330 – 54 T).[7]

Subcommittee XI on Chemical Analysis (W. P. Tyler, chairman) expects soon to complete work on a method for determination of iron in crude natural rubber and GR-S which will be presented to the Society for inclusion in the Methods of Chemical Analysis (D 297 – 54 T).[7]

Subcommittee XII on Crude Natural Rubber (Norman Bekkedahl, chairman) has found that, if a lot of 10 tons of rubber obtained from a single lot of blended latex from a single plantation does not have sufficient uniformity for use as a standard sample, it can be made sufficiently uniform by blending in a Banbury mixer. This conclusion was reached through experiments conducted on blending smoked sheet in a Banbury mixer at The Goodyear Tire and Rubber Co. The problem of establishing a source of standard rubber samples is now a financial one rather than a technical difficulty.

Subcommittee XX on Adhesion Tests (H. H. Irvin, chairman) is completing a round-robin test program on a proposed revision of Method A of the Tentative Methods of Test for Adhesion of Vulcanized Rubber to Metal (D 429 – 47 T). It hopes to have this revision ready for presentation to the Society through the Administrative Committee on Standards within the next few months.

Subcommittee XXII on Cellular Rubbers (H. G. Bimmerman, chairman) has given considerable attention to the problem of test methods for elastomeric cellular products made from vinyl resins and polyurethane elastomers. These materials are becoming increasingly important, and the need for suitable standard test methods and specifications is evident. Other organizations, including the Society of Automotive Engineers, The Rubber Manufacturers Association, Society of Plastics Engineers, and the Society of the Plastics Industry, as well as other technical committees in ASTM, are interested in this matter. At a recent conference of the interested groups, it was recommended that a coordinating committee be set up to allocate the activities to the various groups and to facilitate exchange of information for both rigid and nonrigid cellular materials. Subcommittee XXII is proceeding with the development of test methods for these materials of the nonrigid type which are replacing the soft cellular rubbers.

Subcommittee XXV on Low-Temperature Tests (R. S. Havenhill, chairman) has nearly completed a revision of the Tentative Recommended Practice for Conditioning of Rubber and Plastic Materials for Low-Temperature Testing (D 832 – 46 T). This revision consists of numerous important changes and additions, including the substitution by "Other Elastomeric" for the word "Plastic" in the title, the bringing of the section on crystallization up to date, and the addition of details on a liquid bath. It is expected that the revision can be presented to the Society in the near future.

Subcommittee XXVI on Processibility Tests (R. H. Taylor, chairman) expects to have revisions ready soon for presentation to the Society through the Administrative Committee on Standards of the Tentative Method of Test for Viscosity of Rubber and Rubber-like Materials by the Shearing Disk Viscometer (D 927 – 53 T)[7] and for Curing Characteristics of Vulcanizable Mixtures During Heating by the Shearing Disk Viscometer (D 1077 – 49 T).[7] In the former, the optional use of integral, radially grooved dies will probably be permitted, and a note will probably be added cautioning against unqualified acceptance of Mooney values determined on the so-called high molecular weight polymers. In the latter method, the use of die temperatures instead of cavity temperatures when integral, radially grooved dies are employed will probably be permitted if the type of die and method of temperature measurement are included in the report.

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[7] See Editorial Note, p. 503.

Subcommittee XXVIII on Statistical Quality Control (E. M. Bader, chairman) expects to present to Committee D-11 at the Annual Meeting a proposed Tentative Recommended Practice for Conducting Interlaboratory Tests of Rubber and Rubber-Like Materials. This tentative which describes the general principles for conducting interlaboratory tests has been subjected to intensive study, criticism, and revision by members of the subcommittee and other statistical experts. When presented to the Society later in the year and published, this tentative will fill a real need in guiding the various subcommittees of Committee D-11 in their planning of round-robin test programs so that the maximum value can be realized from the data obtained which is commensurate with the large expenditures of both time and money required for such programs.

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This report has been submitted to letter ballot of the committee, which consists of 238 members; 140 members returned their ballots, of whom 130 have voted affirmatively and 0 negatively.

Respectfully submitted on behalf of the committee,

S. COLLIER,
Chairman.

ARTHUR W. CARPENTER,
Secretary

EDITORIAL NOTE

Subsequent to the Annual Meeting, Committee D-11 presented to the Society through the Administrative Committee on Standards the following recommendations:

Revision of Tentative Methods for:

Chemical Analysis of Rubber Products (D 297 – 54 T),

Revision of Tentative Method of Test for:

Indentation of Rubber by Means of a Durometer (D 676 – 49 T),
Resistance to Accelerated Light Aging of Rubber Compounds (D 750 – 55 T),
Viscosity of Rubber and Rubber-like Materials by the Shearing Disc Viscometer (D 927 – 53 T),
Curing Characteristics of Vulcanized Mixtures During Heating by the Shearing Disc Viscometer (D 1077 – 49 T),
Accelerated Ozone Cracking of Vulcanized Rubber (D 1149 – 51 T),

Revision of Tentative Specifications for:

Rubber and Synthetic Rubber Compounds for Automotive and Aeronautical Applications (D 735 – 54 T), and
Sheet Rubber Packing (D 1330 – 54 T).

The revision of Method D 1149 was accepted by the Standards Committee on January 16, 1956, and the remaining recommendations were accepted on December 19, 1955. The revised methods and specifications appear in the 1955 Book of ASTM Standards, Part 6, and in the 1956 Compilation of ASTM Standards on Rubber Products.

REPORT OF COMMITTEE D-12

ON

SOAPS AND OTHER DETERGENTS*

Committee D-12 on Soaps and Other Detergents held one meeting during the year: on March 14 and 15, 1955, in New York, N. Y.

Resignations regretfully accepted during the year were those of H. R. Suter, secretary; R. Bernstein, chairman of Subcommittee T-2 on Analysis of Synthetic Detergents; and J. A. Woodhead of the Advisory Committee. New appointments are E. W. Colt, secretary, and M. F. Graham to the Advisory Committee.

Notice of the passing of L. F. Hoyt, long-time active member of the committee, was received with sorrow.

At the present time, the committee consist of 117 members, of whom 57 are classified as producers, 35 as consumers, and 25 as general interest members, with 5 consulting members.

NEW TENTATIVES

The committee recommends that the following methods of test be accepted for publication as tentative:[1]

Methods for Analysis of Sodium Triphosphate, and

Method of Aerated Total Immersion Corrosion Test for Metal Cleaners.

REVISION OF STANDARD AND REVERSION TO TENTATIVE

The committee recommends that the following standards be revised as indicated and reverted to tentative status:

Specifications for Trisodium Phosphate (D 538 – 44):[2]

Section 2.—Change to read as follows:

2. Trisodium phosphate shall be a white uniform product in one of the following types, as specified by the purchaser:

Type I.—Anhydrous powder or granules.

Type II.—Granular material corresponding approximately to the formula $Na_3PO_4 \cdot H_2O$.

Type III.—Flake or crystalline material corresponding approximately to the formula $Na_3PO_4 \cdot 12H_2O$.

Section 3.—Change the table of requirements for chemical composition to read as follows:

	Type I		Type II		Type III	
	Min	Max	Min	Max	Min	Max
Trisodium phosphate:						
Calculated as Na_3PO_4 from P_2O_5, per cent	97	...	...	...	...	...
Calculated as $Na_3PO_4 \cdot H_2O$ from P_2O_5, per cent	...	...	97	...	...	...
Calculated as $Na_3PO_4 \cdot 12H_2O$ from P_2O_5, per cent	...	...	...	...	97	...
Total alkalinity to methyl orange, as Na_2O, per cent	36	39	32	35	16	19
Phosphoric anhydride (P_2O_5), per cent	42.0	...	38.0	...	18.1	...
Matter insoluble in water, per cent	...	0.1	...	0.1	...	0.1

Section 4(a).—In line 10, change the statement in parentheses to read as follows:

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* Presented at the Fifty-eighth Annual Meeting of the Society, June 26–July 1, 1955.

[1] The new tentatives appear in the 1955 Book of ASTM Standards, Part 7.

[2] 1952 Book of ASTM Standards, Part 7.

(Calculated from the determined P_2O_5 as Na_3PO_4 for type I, as $Na_3PO_4 \cdot H_2O$ for type II, or as $Na_3PO_4 \cdot 12H_2O$ for type III.)

Change the definition of "T" to read as follows:

T = total trisodium phosphate calculated as Na_3PO_4 for type I, as $Na_3PO_4 \cdot H_2O$ for type II, or as $Na_3PO_4 \cdot 12H_2O$ for type III.

Specifications for Sodium Metasilicate (D 537 – 41):[2]

Section 2.—Change to read as follows:

2. Sodium metasilicate shall be a uniform product in one of the following forms as specified by the purchaser:

Type I.—White granular or crystalline material.

Type II.—Granular anhydrous material.

Section 3.—Change to read as follows:

3. Sodium metasilicate, as received, shall conform to the following requirements as to chemical composition:

	Type I		Type II	
	Min	Max	Min	Max
Sodium metasilicate:				
Calculated as $Na_2SiO_3 \cdot 5H_2O$, per cent	98.0	...	...	...
Calculated as Na_2SiO_3, per cent	...	...	91.5	...
Total alkalinity to methyl orange, as Na_2O, per cent	28.5	30.0	50.0	52.0
Total silica as SiO_2, per cent	27.5	29.0	45.0	...
Matter insoluble in water, per cent	...	0.2	...	0.3
Carbonates as CO_2, per cent	...	1.2	...	2.0

Section 4(a).—Change the second sentence to read: "Therefore, the calculation of net weight shall be based upon a product containing 98 per cent of sodium metasilicate calculated as $Na_2SiO_3 \cdot 5H_2O$ for type I or 91.5 per cent of sodium metasilicate calculated as Na_2SiO_3 for type II."

Replace the formula and legend at the end of the paragraph with the following:

$$W = \frac{R \times T}{98} \text{ for type I}$$

$$W = \frac{R \times T'}{91.5} \text{ for type II}$$

where:

W = net weight of the material to be paid for,

R = net weight of the material as received,

T = total sodium metasilicate calculated as $Na_2SiO_3 \cdot 5H_2O$, and

T' = total sodium metasilicate calculated as Na_2SiO_3.

Specifications for Soda Ash (D 458 – 39):[2]

Section 5.—Delete the words "Types of" in the introductory sentence. Delete the reference to extra light soda ash from the tabulation at the end of this Section.

ADOPTION OF TENTATIVE AS STANDARD WITHOUT REVISION

The committee recommends that the Tentative Methods for Analysis of Sodium Bicarbonate (**D 501 – 53 T**)[3] be approved for reference to letter ballot of the Society for adoption as standard without change.

ADOPTION OF TENTATIVE AS STANDARD WITH REVISION

The committee recommends that the Tentative Specifications for Milled Toilet Soap (**D 455 – 53 T**)[3] be approved for reference to letter ballot of the Society for adoption as standard with the following change:

Section 3.—Change the minimum per cent of anhydrous soap content from "81.0" to read "83.0."

REVISIONS OF STANDARDS, IMMEDIATE ADOPTION

The committee recommends for immediate adoption revisions in the following standards, and accordingly asks for the necessary nine-tenths affirmative vote at the Annual Meeting in order that the revisions may be referred to letter ballot of the Society:

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[3] 1953 Supplement to Book of ASTM Standards, Part 7.

Methods of Chemical Analysis of Sulfonated and Sulfated Oils (D 500 - 45):[2]

Section 43(b).—In line 7, change "125 to 130 C" to read "105 ± 2C."

Definition of Terms Relating to Soaps and Other Detergents (D 459 - 52):[2]

Revise to include the following new definitions:

Brightening Agent.—An essentially colorless material which absorbs ultraviolet radiation and emits light of a bluish hue complementary to the yellowish tint of the off-white substrate on which it is present.

Optical Whitening Agent.—See Brightening Agent.

Brightener.—See Brightening Agent.

Optical Bleach.—See Brightening Agent.

REAPPROVAL OF STANDARDS

The committee recommends the reapproval of the following standard specifications and methods:

Standard Specifications for:

White Floating Toilet Soap (**D 499 - 48**),
Built Soap, Powdered (**D 533 - 44**),
Alkaline Soap Powder (**D 534 - 42**),
Olive Oil Solid Soap (Type A, Straight; Type B, Blended) (**D 592 - 42**),
Salt-Water Soap (**D 593 - 42**),
Olive Oil Chip Soap (Type A, Straight; Type B, Blended) (**D 630 - 52**),
Compound Chip Soap (With Rosin) (**D 690 - 48**),
Compound Powdered Soap (Granulated, with Rosin) (**D 691 - 44**),
Caustic Soda (Anhydrous) (**D 456 - 39**),
Modified Soda (Sesquicarbonate Type) (**D 457 - 39**),
Sodium Sesquisilicate (**D 594 - 41**), and
Tetrasodium Pyrosphosphate (Anhydrous) (**D 595 - 45**).

Standard Methods of:

Test for Particle Size of Soaps and Other Detergents (**D 502 - 39**),
Chemical Analysis of Soaps Containing Synthetic Detergents (**D 820 - 46**),
Chemical Analysis of Industrial Metal Cleaning Compositions (**D 800 - 45**), and
Total Immersion Corrosion Test of Water-Soluble Aluminum Cleaners (**D 930 - 49**).

TENTATIVES CONTINUED WITHOUT REVISION

The committee recommends that the following methods be continued as tentative without revision:

Tentative Method of:

Test for Buffering Action of Metal Cleaners (**D 1279 - 53 T**),
Total Immersion Corrosion Test for Soak Tank Metal Cleaners (**D 1280 - 53 T**), and
Test for Rinsing Properties of Metal Cleaners (**D 1281 - 53 T**).

The recommendations in this report have been submitted to letter ballot of the committee, the results of which will be reported at the Annual Meeting.[4]

ACTIVITIES OF SUBCOMMITTEES

Subcommittee T-1 on Soap Analysis (E. W. Blank, chairman), which functions as a joint committee with the American Oil Chemists' Society, has developed an improved method for determination of sodium chloride in soaps. Development of a spectrophotometric method for copper in soap is nearly completed and cooperative tests are to be made. A task group under C. A. Gerardi is in the process of critically reviewing the present methods of analysis appearing in the Method of Sampling and Chemical Analysis of Soaps and Soap Products (D 460) and Methods of Chemical Analysis of Soaps Containing Synthetic Detergents (D 820) in the light of newly developed techniques and tools.

Subcommittee T-2 on Analysis of Synthetic Detergents (R. Bernstein, chairman).—A task group is investigating solvent techniques for separating detergent from builders, and another task group has worked out a promising technique for taking infrared spectra based upon dispersion of the surfactant sample in a potassium bromide wafer.

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[4] The letter ballot vote on these recommendations was favorable; the results of the vote are on record at ASTM Headquarters.

Subcommittee T-3 on Analysis of Dry Cleaning Materials (G. P. Fulton, chairman).—A proposed method for determination of moisture in dry-cleaning detergents was developed which is to be evaluated during the year.

Subcommittee T-4 on Analysis of Alkaline Detergents (W. H. Koch, chairman).—Work is being undertaken on a method for analysis of dry polyphosphates as a direct estimation.

Subcommittee T-5 on Physical Testing (A. M. Schwartz, chairman).—Task groups are currently at work on the following subjects: methods of redeposition, wetting methods, measurement of reflectance, rewetting methods, and performance of brightening agents. Bibliographical Abstracts on Evaluation of Brightening Agents for Detergent Usage was prepared for publication by L. E. Weeks.[5]

Subcommittee T-6 on Metal Cleaning (J. C. Harris, chairman).—A task group under H. A. Kafarski on automotive industries cleaning has tentatively established a procedure for the evaluation of cleaners in spray power washers.

A procedure for water-soluble corrosion test on vitreous enamel surfaces is under review.

A critical re-evaluation of Methods of Chemical Analysis of Industrial Metal Cleaning Compositions (D 800 – 45) is to be made with reference to improvement and correlation with existent similar methods.

Subcommittee S-1 on Specifications for Soap (F. Krassner, chairman).—Consideration will be given to revision of specifications for Chip or Granular Soap for Low-Temperature Washing (Low and Medium Titer) (D 1111 – 53), possibly to include 1 to 3 per cent of rosin.

Subcommittee S-4 on Specifications for Alkaline Detergents (W. Stericker, chairman) reports that specifications for orthosilicate and sodium tripolyphosphate will be undertaken.

Subcommittee G-1 Advisory (J. C. Harris, chairman) appointed V. C. Mehlenbacher to work with the American Oil Chemists' Society in the formation of a joint committee whose duties would combine the activities of Subcommittees T-1 and T-2 on Analysis of Soaps and Analysis of Synthetic Detergents with the equivalent groups of AOCS. A task group is working on a certificate or award for outstanding effort in the detergent field. The members of Committee D-12 will be circularized for their opinions as to procedure.

Subcommittee G-5 on Program Planning (R. B. Mitchell, chairman) prepared the program presented at the March meeting of the committee which included presentation of the following technical papers:

"A Method of Testing Detergents for On Location Rug Cleaning," by James W. Rice,
"Review of Literature on Theory and Practice of Redeposition Methods," by M. G. Kramer, H. Paitchel, and W. A. Tidridge,
"Advances in Reflectance Methods as Applied to Detergency," by R. S. Hunter,
"Nuclear-Chicago Radioactive Tests Swatches," by O. K. Neville, and
"Dishwashing Detergent Evaluation," by H. T. Brumleve, Jr.

This report has been submitted to letter ballot of the committee, which consists of 117 members; 76 members returned their ballots, of whom 74 have voted affirmatively and 2 negatively.

Respectfully submitted on behalf of the committee,

J. C. HARRIS,
Chairman.

H. R. SUTER,
Secretary.

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[5] Issued as separate publication *ASTM STP No. 177.*

REPORT OF COMMITTEE D-13

ON

TEXTILE MATERIALS*

Committee D-13 on Textile Materials held two meetings during the year: on October 19 to 22, 1954, in Washington, D. C., and on March 15 to 18, 1955, in New York, N. Y. Four full days are now required to provide for meetings of task groups as well as subcommittees and sections.

The Honorable Walter Williams, Under Secretary of the Department of Commerce, was the speaker at a dinner held in connection with the Washington meeting. At the New York meeting, the Harold DeWitt Smith Memorial Medal for 1955 was presented to John H. Dillon, Director, Textile Research Institute.

Interest in general test methods for yarns and fabrics has grown with the practice in many mills of processing more than one kind of fiber and with the increased use of fiber blends in textile products. To better meet the current needs of members, the Advisory Committee decided to give subcommittee status to work on general test methods for fibers, for yarns, for fabrics, and for chemical test methods. The existing subcommittees on cotton and its products, and on wool and its products will continue to deal with the special test methods required for these fibers and other special problems of the cotton and wool industries.

A new Subcommittee B-6 on ISO/TC 38, was appointed to deal in ASTM with the work on textiles of the International Organization for Standardization. A. G. Scroggie was appointed chairman. J. A. Truitt was appointed chairman of Subcommittee B-2.

A Nominating Committee for officers for the 1956–1958 term was appointed by the Advisory Committee as follows: R. T. Kropf, Chairman, J. S. Jacobs, and C. A. Baker.

A report on Measurement of Shrinkage in Laundering of Knit Fabrics, which describes the cooperative studies and presents the test data that resulted in the development of the Methods of Test for Shrinkage in Laundering of Knit Cotton Fabrics (D 1231 – 54), Shrinkage in Laundering of Knit Rayon Fabrics (D 1232 – 54), and Relaxation and Felting Shrinkage in Laundering of Stabilized Knit Wool Fabrics (D 1284 – 53 T), has been prepared by the Task Group on Knit Fabrics (Hazel M. Fletcher, chairman) of Subcommittee B-1 on Test Methods.[1]

Recommendations Affecting Standards

Committee D-13 is presenting for publication 3 proposed methods as information, 8 new tentatives, and is recommending the revision of 6 tentatives, tentative revision of 3 standards, adoption as standard of several definitions, immediate revision of two standards, adoption of one tentative as standard, revision and reversion to tentative of 4 standards, and withdrawal of one tentative.

The Standards and Tentatives affected, together with the revisions recommended, are listed in detail in Appendix I.[2]

*** Presented at the Fifty-eighth Annual Meeting of the Society, June 26–July 1, 1955.**

[1] This report is published in the compilation of "ASTM Standards on Textile Materials," January, 1956, p. 686.

[2] See p. 510.

All other standards and tentatives not specifically referred to are being actively studied by the respective sponsoring subcommittees and it is recommended that they be continued in their present status.

The recommendations in this report have been submitted to letter ballot of the committee, the results of which will be reported at the Annual Meeting.[3]

This report has been submitted to letter ballot of the committee, which consists of 367 members; 135 returned their ballots, all of whom have voted affirmatively.

Respectfully submitted on behalf of the committee,

W. D. APPEL,
Chairman.

W. H. WHITCOMB,
Secretary.

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[3] The letter ballot vote on these recommendations was favorable; the results of the vote are on record at ASTM Headquarters.

EDITORIAL NOTE

Subsequent to the 1955 Annual Meeting, Committee D-13 presented to the Society through the Administrative Committee on Standards the following recommendations:

Tentative Methods of Test for:

Spun and Filament Yarns Made Wholly or in Part of Man-Made Organic Base Fibers (D 1380 - 55 T),
Stiffness of Fabrics (D 1388 - 55 T),

Revision of Tentative Specifications for:

Fire-Retardant Properties of Treated Textile Fabrics (D 626 - 41 T),

Revision and Reversion to Tentative of Standard Methods of:

Quantitative Analysis of Textiles (D 629 - 54),

Withdrawal of Methods of:

Testing Continuous Filament Man-Made Organic Base Yarns (D 258 - 52 T),
Testing and Tolerances for Spun Rayon and Acetate Yarns and Threads (D 507 - 44), and
Testing and Tolerances for Yarns Spun from Mixed Fibers (D 508 - 53).

The recommendations for the publication of new Tentative Methods D 1380 and the withdrawal of Methods D 258, D 507, and D 508 were accepted by the Standards Committee on September 15, 1955; the remaining recommendations were accepted January 4, 1956. The new and revised methods and specifications appear in the 1955 Book of ASTM Standards, Part 7, and in the January, 1956, Compilation of "ASTM Standards on Textile Materials."

APPENDIX I

RECOMMENDATIONS AFFECTING STANDARDS FOR TEXTILE MATERIALS

In this Appendix are given proposed revisions in certain standards and tentatives covering textile materials. These standards and tentatives appear in their present form in the 1952 Book of ASTM Standards, Part 7, and in the 1953 and 1954 Supplements to Book of ASTM Standards, Part 7.

PROPOSED METHODS TO BE PUBLISHED AS INFORMATION

Committee D-13 recommends the following three methods for publication as information, as appended hereto:[1]

Proposed Method of Test for Linear Density of Textile Fibers by the Vibroscope,
Proposed Method of Test for Cotton Content of Asbestos Textile Materials (Referee Method), and
Proposed Method for Analysis of Asbestos-Glass Fiber Textile Materials.

NEW TENTATIVES

The committee recommends the following eight methods and specifications for publication as tentative, as appended hereto,[2] except for one method as indicated:

Tests for Warp Knit Fabrics,
Test for Pilling Propensity of Textile Fabrics,
Test for Wide Elastic Fabrics,
Test for Abrasion Resistance of Textile Yarns,
Test for Absorbency Time and Absorptive Capacity of Nonwoven Fabrics,
Test for Maturity of Cotton Fibers (Polarized Light Method), to replace the procedure in Methods D 414,
Specifications and Methods of Test for Fineness of Mohair Tops, and
Test for Fineness of Cotton Fibers by Resistance to Air Flow (Arealometer Method), as published as information[3] in 1954 in Appendix VII of the compilation of ASTM Standards on Textile Materials, October, 1954, with Section 1 on Scope revised to read as follows, including the addition of a note:

> **1.** *Scope.*—This method of test is applicable to the determination of the specific area of loose cotton fibers, regardless of source, and of immaturity ratio of ginned lint, using the arealometer for measuring the resistance to air flow of a plug of cotton fibers when tested under prescribed conditions. In addition, formulas are given for calculating the average perimeter, wall thickness, and weight per inch from these data.
>
> NOTE.—Processed fibers tend to give slightly higher values of immaturity ratio than ginned lint. The formulas in Section 10 are based on values obtained from ginned lint.

REVISION OF TENTATIVES

The committee recommends the revisions of five tentatives as follows:

Tentative Specifications and Methods of Test for Fineness of Wool Tops (D 472 - 53 T),[3] revise as appended hereto.[4]

Tentative Methods of Test for Fineness of Wool (D 419 - 50 T),[5] revise as appended hereto.[4]

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[1] The proposed methods appear in the January 1956 ASTM Compilation of Standards on Textile Materials.

[2] The new tentatives appear in the 1955 Book of ASTM Standards, Part 7.

[3] 1953 Supplement to Book of ASTM Standards, Part 7.

[4] The revised tentative appears in the 1955 Book of ASTM Standards, Part 7.

[5] 1952 Book of ASTM Standards, Part 7.

Tentative Method of Test for Resistance of Pile Floor Coverings to Insect Pest Damage (D 1116 – 50 T),[5] revise as follows:

Section 8.—Change to read as follows:

8. *Classification.*—A minimum of 30 mg of excrement from the untreated control carpet is necessary as an indication of larvae activity. If this minimum is not attained, the test is invalid and should be repeated. Carpets tested under conditions which satisfy this requirement can then be classified as follows:

(*a*) Calculate the percentage protection, excrement method, calculated as follows:

$$\text{Protection, per cent} = 100 - \frac{100A}{B}$$

where:

A = weight of excrement on treated specimen, in milligrams, and

B = weight of excrement on untreated specimen, in milligrams.

(*b*) Classification shall then be according to the following table:

Protection, per cent	Visual Damage	Insect-Resistance Classification
100 to 66.7	none	resistant
66.7 to 50	none	semiresistant
50 to 0	some	nonresistant

Tentative Methods of Core Sampling of Raw Wool in Packages for Determination of Percentages of Clean Wool Fiber Present (D 1060 – 54 T),[6] revise as follows:

Table I.—Change Class C (*1*) to read as follows:

	σ_w	σ_b
(*1*) Washed or greasy, not burry:		
Aleppo	3.0	2.5
B. A.	3.5	2.5
Blackface	4.0	3.5
India (other than Vicanere):		
White	2.5	1.5
Colored	3.5	3.0
Iran	3.5	3.5
Iraq	3.5	2.0
N. Z. Crutchings	3.5	5.0
Pakistan	2.0	2.0
Vicanere	3.0	2.5

Table II.—Add to Table II, in the appropriate order, the sample schedules shown in the accompanying Table I.

Tentative Methods of Test for Abrasion Resistance of Textile Fabrics (D 1175 – 51 T),[5] revision of Methods B and D as appended hereto.[4]

TENTATIVE REVISIONS OF STANDARDS

The committee recommends the following tentative revisions of three standards:

Standard Methods of Testing Pile Floor Coverings (D 418 – 42):[5]

Sections 18 to 22 Inclusive.—Delete, and substitute the following:

18. *Fastness of Color to Light.*—Colorfastness to light of pile floor coverings shall be measured by the Method of Test for Colorfastness to Light of Textiles (ASTM Designation: D 506), with the following exceptions:

(*a*) *Test Specimens.*—Test specimens for the determination of fastness to light shall be approximately 2½ by 4 in., and so cut that the 4-in. dimension shall be parallel to the direction of the warp.

(*b*) *Specimen Holders.*—The frame for holding the test specimens shall be so constructed as to permit the mounting of the specimen in such a manner that it cannot bend away from the front of the frame at any point, that the pile touches the front of the frame lightly, that the lower part of the specimen is exposed, and that the exposed area, approximately 1½ by 2 in., is completely surrounded by an unexposed area.[a]

[a] Suitable specimen holders for pile fabrics may be obtained from the Atlas Electric Devices Co., Chicago, Ill.

Standard Methods of Testing and Tolerances for Certain Wool and Part Wool Fabrics (D 462 – 53):[3]

The committee recommends that the tentative revision of this method,[6] issued in June, 1954, be revised to read as follows:

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[6] 1954 Supplement to Book of ASTM Standards, Part 7.

Section 9.—Change this section from its present form: namely,

> 9. *Weight.*—The weight of the fabric shall be determined in accordance with Section 6 of Standard Methods D 39.

to read as follows:

> 9. *Weight.*—The weight of the fabric shall be determined in accordance with Section 6 of Methods D 39, or by the following alternate method:
>
> (*a*) *Alternate Method.*—A specimen having an area of at least 20 sq in. (or a number of specimens not less than 2 in. square and having a total area of at least 20 sq in.) shall be cut from the fabric The oven-dry weight shall be determined on this specimen. Unless a specimen the full width of the fabric is used, no specimen shall be taken nearer the selvedge than one-tenth the width of the fabric.
>
> NOTE.—This method is intended for use when a small sample of fabric is sent to the laboratory for test. The result is considered to be applicable to the sample, but not to the

TABLE I.—ADDITIONAL SAMPLING SCHEDULES FOR A PRECISION OF ±1.0 PER CENT AT A STATISTICAL PROBABILITY OF 0.95.

(Additions to Table II, Tentative Methods D 1060.)

σ_w	σ_b	k	25	50	75	100	150	200	300	500	750	1000
1.5	1.0	1	12	12	13	13	13	13	13	13	13	13
2.5	1.0	1	25	27	28	28	29	29	29	29	29	29
		2	15	16	16	16	16	17	17	17	17	17
3.0	3.0	1	b	42	49	53	58	61	65	68	69	70
		2	23	32	37	40	44	46	49	51	52	53
3.0	4.5	1	b	45	57	65	76	84	93	101	106	109
		2	24	38	48	55	65	71	78	86	90	92
3.5	3.5	1	b	50	60	66	74	79	85	90	92	94
		2	25	38	45	50	56	59	64	67	69	70
		4	21	31	37	42	47	50	53	56	58	59
3.5	5.0	1	b	50	64	75	90	100	112	125	132	136
		2	25	42	54	63	75	84	94	105	111	114
		4	23	38	49	57	68	75	85	94	99	102
4.5	1.5	1	b	b	b	83	85	87	88	89	89	90
		2	b	42	45	46	47	48	48	49	49	49
		4	22	25	27	27	28	28	29	29	29	29
4.5	3.5	1	b	b	b	87	97	104	111	118	121	123
		2	b	46	57	63	71	76	81	86	88	90
		4	24	35	42	47	53	56	60	63	65	66
4.5	5.0	1	b	b	b	91	109	121	136	151	160	165
		2	b	47	61	71	85	94	106	117	124	128
		4	25	40	52	61	73	81	91	101	107	110
5.5	2.5	1	b	b	b	b	126	130	135	139	142	143
		2	b	b	65	69	74	76	79	82	83	84
		4	b	37	42	45	48	50	51	52	54	54
		6	23	31	34	37	39	41	42	43	44	44
5.5	3.5	1	b	b	b	b	128	136	146	155	160	162
		2	b	b	67	74	83	88	95	100	103	105
		4	b	40	48	54	60	64	69	73	75	76
		6	24	35	42	47	53	56	60	63	65	66
5.5	5.0	1	b	b	b	b	133	148	166	185	195	201
		2	b	b	b	81	97	107	121	134	142	146
		4	b	44	56	66	79	87	98	109	115	119
		6	24	40	52	60	73	81	91	101	106	110

piece or lot of goods from which the sample was taken, unless the number of samples and method of sampling are specified and agreed upon by those concerned.

(*b*) *Reference Weight* (*Including Standard Regain*).—Reference weight of all woven wool fabrics or woven fabrics of blends containing wool is the oven-dry weight of the fabric plus its standard regain as calculated, using the formula given in Paragraph (*c*).

(*c*) *Standard Regain.*—The standard moisture regain for woven fabrics containing all wool shall be 13.6 per cent. The standard regains of fibers other than wool shall be as follows:

Fibers Other Than Wool	Standard Regain
Cupramonium	11.0
Silk	11.0
Viscose	11.0
Vicara	10.0
Cotton	7.0
Acetate	6.5
Nylon	4.5
Orlon	1.5
Dynel	1.0
Acrilan	1.0
Dacron	1.0

In the case of synthetic fibers not listed above, the standard regain value as established by the manufacturer shall apply.

The standard moisture regain for woven fabrics composed of blends containing wool shall be calculated as follows:

Standard regain, per cent

$$= \frac{(W \times 13.6) + (A \times R_a) + (B \times R_b) + (N \times R_n)}{100}$$

where:

W = percentage of wool (oven-dry basis),

$A, B, \ldots N$ = percentage (oven-dry basis) of fibers a, b, n, respectively, and

$R_a, R_b, \ldots R_n$ = percentage of standard regains of fibers $a, b, \ldots n$, respectively.

Standard Definitions of Terms Relating to Textile Materials (D 123 – 54):[6]

The committee recommends the following new and revised definitions of terms for publication as tentative:

Bleaching, n.—The procedure, other than by scouring only, of improving the whiteness of a textile material by oxidation or reduction of the coloring material.

NOTE.—Optical bleaching is the procedure of adding extraneous substances to produce the illusion of whiteness.

Bright, adj.: 1. *General.*—Characterized by a high degree of luster; brilliant; opposite of dull; relatively vivid in color.

2. *Textile.*—High in luster, that is, showing a relatively large tendency to concentrate reflected light in specific directions and relatively little tendency to scatter light diffusely; opposite of dull or matte.

3. *Man-Made Fibers.*—Term applied to textile materials whose normal luster has not been reduced by physical or chemical means.

Dull, adj.: 1. *General.*—Opposite of bright or vivid; cloudy.

2. *Textile.*—Low in luster, that is, showing relatively little tendency to concentrate reflected light in specific directions, and relatively great tendency to scatter light diffusely; matte; opposite of bright.

3. *Man-Made Fibers.*—Term applied to textile materials whose normal luster has been reduced by physical or chemical means.

Gage (*also Gauge*), *n.:* 4. *Warp Knitting.*—Simplex, Tricot, Milanese—Number of needles per English inch. Raschel, Kayloom—Twice the number of needles per English inch.

NOTE.—28-gauge English inch equals 26-gauge Saxon inch.

Gaiting, n. Warp Knitting.—The setting of a guide bar one or more needle spaces to the right or left in order to increase the pattern possibilities.

Grade, n. Warp Knitting.—A term used to indicate the defect index evaluation of fabric determined by the number of defects per unit, preferably per pound, per linear yard, or per square yard.

Inches per Rack (*IPR*), *Warp Knitting.*—The length of fabric in one rack measured on the machine under operating take-up tension.

NOTE.—The phrase "inches per rack" is recommended for use in place of the word "quality," previously used for this concept.

Luster, n.—That property of a textile material which exhibits differences in intensity of light reflected from within a given area of material when the angles of illumination or viewing are changed.

NOTE.—Frequently associated with the adjectives "bright" or "dull" to distinguish between these varieties of man-made fibers.

Rack, n. Warp Knitting.—A unit of length measure consisting of 480 courses.

Weight, n. Warp Knitting.—The number of yards per pound of finished fabric.

NOTE.—This could be square yards per pound or linear yards per pound stating the width.

Yarn Unevenness, n.—It is proposed to shorten this item to include all textile strands, with the following changes: Revise Item (1), "Linear Unevenness (LUE)," to read as follows, and delete the remaining Items (2) through (6), since these are simply mathematical derivatives of the basic term "unevenness."

Unevenness (U), n., Yarn, Roving, Sliver, etc.—The nonuniformity of the linear density of a continuous strand or portion of a strand.

NOTE.—An estimate of nonuniformity of linear density is usually made from measurements of some other property of the strand, such as variations in compressed cross-sectional area, variations in profile (usually measured photoelectrically), or variations in those properties of the strand which change the capacity of a condenser when passed between the plates.

Yield, n. Warp Knitting.—The number of finished square yards per pound of gray fabric.

REVISION OF STANDARD, IMMEDIATE ADOPTION

The committee recommends for immediate adoption the following revisions of two standards, and accordingly asks for the necessary nine tenths affirmative vote at the Annual Meeting in order that these recommendations may be submitted to letter ballot of the Society:

Standard Definitions of Terms Relating to Textile Materials (D 123 – 54):[6]

Roving, n.—Change the last sentence to read as follows:

In spun yarn systems, the product of the stage, or stages, just prior to spinning.

Standard Method of Test for Colorfastness to Light of Textiles (D 506 – 52):[5]

Section 1.—Delete the last sentence.

Section 4(a).—Beginning with the seventh sentence, delete to "Notes," and substitute the following:

A blower unit thermostatically controlled by the ambient air temperature provides a flow of air over the specimens and through the test chamber. The air is filtered and humidified by circulation over wicks saturated with water. For textiles, the machine should be adjusted so that it produces approximately 20 standard fading hours in 20 clock hours of operation at a Black Panel Temperature of not over 165 F (74 C) (Note 5).

Section 4(a), Note 3.—Delete, and change "Notes 4 and 5" to "Notes 3 and 4."

Section 4(a), Note 5.—Delete, and substitute the following:

NOTE 4.—The fading rate is affected by both the intensity of the arc lamp and the Black Panel Temperature. Instructions for adjusting the intensity of radiation are included in the operating manual currently being supplied by the manufacturer. As the radiation intensity is varied, it will be necessary to adjust the setting of the thermostat to maintain the desired 165 F Black Panel Temperature. Black Panel Temperatures in excess of 165 F usually indicate too high a radiation intensity.

Section 4(a).—Substitute the following new Note 5:

NOTE 5.—The standard Black Panel Thermometer Unit consists of a metal panel $2\frac{3}{4}$ by $5\frac{7}{8}$ in., with the sensitive portion of the stem of a bimetallic dial type thermometer mechanically fastened to the center of one side of the plate. The plate and the thermometer stem have been sprayed with two coats of a baked light-resistant black enamel. The unit is mounted in a suitable holder so that its enameled face is toward the arc and is at the same distance from the arc as the faces of the test specimens. As in the test specimens, the temperatures indicated by the Black Panel Thermometer Unit are thus affected by the intensity of the radiation and the amount of heat removed by the air passing over the specimens, as controlled by the blower unit. The Black Panel Thermometer should be checked at least once a year, with respect to the accuracy of the reading as well as the condition of the enamel surface. Careful attention to the cleanliness of the air filter, located in the base of the machine, is necessary for maintenance of the recommended fading rate and Black Panel Temperature.

Appendix.—Delete Sections A1 to

A5 inclusive, and substitute the following:

Calibration of Fading Lamp

A1. (*a*) Light-sensitive paper and a booklet of standard faded strips of it for calibration of commercial fading lamps may be obtained from the National Bureau of Standards, Washington 25, D. C. The standard faded strips are produced in the Bureau's Master Fading Lamp, which is adjusted to produce in 20 hr of exposure just appreciable fading of AATCC Blue Standard Dyeing L4. The booklet contains faded strips exposed for stated intervals of Standard Fading Hours, and is suitable for use in calibrating fading lamps in a length of run about equivalent to the life of a trim of carbons, or 20 Standard Fading Hours.

(*b*) The paper may be used to check the performance of lamps from time to time in order to predict the number of clock hours of exposure that will be required to produce fading corresponding to a specified number of Standard Fading Hours. The more frequently such checks are made, the greater will be the assurance that the lamp is performing as desired.

Procedure

A2. (*a*) Mount a piece of the paper in a specimen holder of the lamp in the usual way (without backing), and place it in the lamp at the time it is started with a new set of carbons. Expose the paper continuously for 20 hr. Remove it and allow it to stand in the dark at room temperature for at least 2 hr in order to cool and to regain its normal moisture from the air. Trim off and discard the unexposed edges, as they may affect the judgment of the fading.

(*b*) Compare the fading of the exposed paper with that of the standard faded strips in the booklet. To do this, hold the booklet in the left hand, allow the pages to flip open one after another, rear cover first, and slip the exposed paper under one standard faded strip after another, being careful to have the standard strip superimposed closely upon the exposed paper, and the grain, that is, the long dimension or "machine" direction of the two, in the same direction. Make the comparison in the light from a daylight fluorescent lamp or equivalent source with illumination of 50 foot-candles or more on the papers. The lamp should be parallel with the long edge of the paper and booklet. The incident light should be at an angle of 45 deg, and the line of sight perpendicular to the surface of the paper. Avoid touching the surfaces of the exposed paper and the standard strips with the fingers, as the surfaces are sensitive to moisture, and soil easily.

(*c*) From the comparison, estimate the exposure in Standard Fading Hours that would duplicate the fading of the test piece. Obtain a factor for converting clock hours of exposure in the lamp to Standard Fading Hours. For example, if the paper exposed for 20 clock hours faded to an extent considered to fall half-way between the 16 and 20 SFH strips in the booklet, that is, 18 SFH, the factor would be 18/20 or 0.9. Credit textiles exposed in the machine for a given number of clock hours with an exposure in Standard Fading Hours of 0.9 times the clock hours. The recommended fading rate is 20 SFH in 20 clock hours. If the factor is greater than 1.1, the fading rate is considered too high, as it may produce anomalous results. The lamp should then be adjusted to a slower fading rate.

Use of Paper in Testing

A3. (*a*) The lamp calibration outlined in the preceding paragraphs is a suitable basis for timing exposures in routine testing. For more important testing, however, the dosage of radiant energy should be measured with the paper during each test, as the fading rate of a lamp may change from day to day and even during a test. The procedure is illustrated by the following directions for control of a 20-hr exposure. For long exposures, a succession of papers will have to be used and the number of Standard Fading Hours shown by them added together, to obtain the total exposure. In carrying out such tests, the paper should be changed with each change of carbons.

(*b*) Place the textile specimen and two (or more if desired) pieces of the paper in the lamp at the same time, side by side. Remove one of the papers from the lamp about 4 hr before the estimated end of the test, noting the time. Allow this paper to stand in the dark at room temperature for 2 hr, compare the fading with that of the standard faded strips, and obtain the factor for converting clock hours to SFH as already outlined. Use this factor in calculating the time of exposure for the textile under test. The piece of paper left in the lamp with the textile will have received the same radiant-energy exposure as the textile at the end of the test. The actual exposure in SFH at the end of the test will then be obtained by rating the fading of this paper with the standard fading strips in the booklet. The result can be used as evidence that the test was as desired, or sufficiently near to it; or that the test must be repeated.

Reflectance of Faded Papers

A4. Although the paper and booklets are designed for simple visual estimation of the fading, photometric measurements may be used. They are used regularly at the National Bureau of Standards in evaluating the faded strips that go into the booklets. A Hunter Multipurpose Reflectometer (3) with large aperture and amber filter (4) is employed.

Figure 1.—Delete the present Fig. 1.

ADOPTION OF TENTATIVES AS STANDARDS

Definitions of Terms Relating to Textile Materials (D 123 – 54):[6]

The committee proposes that the definitions for the following 12 terms now appearing as tentative in Standard D 123 – 54 be approved for submission to letter ballot of the Society for adoption as standard:

1. Filler,
2. Note under Filling, revise to read:
   NOTE.—Filling yarn is also designated as "weft" and occasionally as "woof." In the United Kingdom the word "filling" corresponds to the word "fillers" in the U. S.
3. Definition (2) under Lea,
4. Lea Skein,
5. Pressley Index,
6. Strength, Tensile,
7. Tape (2), Slide Fasteners,
8. Top,
9. Warp, Ball,
10. Woolen-Spun,
11. Worsted-Spun, and
12. Twist, Direction of.

Tentative General Methods of Testing Cotton Fibers (D 414 – 54 T):[6]

The committee recommends that the method for length by fiber array in Sections 4 to 10 of these methods be revised and issued as standard. The proposed revised Standard Method of Test for Length and Length Distribution of Cotton Fibers by the Array Method is appended hereto.[7]

REVISION OF STANDARD AND REVERSION TO TENTATIVE

The committee recommends that the Standard Method of Test for Fiber Length of Wool (**D 519 – 49**)[5] be reverted to tentative and revised as appended hereto.[4]

WITHDRAWAL OF TENTATIVE

The committee recommends the withdrawal of the Tentative General Methods of Testing Cotton Fibers (**D 414 – 54 T**), since the procedures now included therein have been revised and replaced by the separate methods for testing cotton fibers as mentioned earlier in this report.

EDITORIAL CHANGES

The committee recommends the following editorial changes in the five standards indicated:

Standard Methods of Quantitative Analysis of Textiles (D 629 – 54):[6]

Section 5(*a*).—Change to read as follows:

5(*a*). *Nature of Test.*—This procedure is intended for removing nonfibrous natural constituents of the fiber and substances added by the manufacturer. Starch, China-clay, soaps, some waxes, some nondrying oils, certain resins, and the usual natural constituents are in this category, and are removed by the procedure described. However, general directions for the removal of all possible substances which may be present cannot be included. Some of the newer finishes present special problems. The analyst will have to meet special cases as they arise. When it is necessary to modify the procedure to remove nonfibrous constituents, the analyst shall make sure that purified specimens of the fibers under consideration do not lose weight when subjected to the same treatment. Ordinarily, specimens shall be analyzed in accordance with Paragraphs (*b*) to (*e*).

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[7] The revised standard appears in the 1955 Book of ASTM Standards, Part 7.

Section 5(c).—Substitute the following for the first four sentences:

Extract the dried specimen for 2 hr with carbon tetrachloride in a Soxhlet or similar extractor, syphoning over a minimum of six times. Air-dry the specimen, and wash by repeated immersion in hot distilled water, squeezing between each immersion. Where necessary, immerse the specimen in an aqueous solution of a starch and protein solubilizing enzyme preparation.

Standard Specifications and Methods of Test for Asbestos Yarns (D 299 – 54),[5] for Asbestos Tape for Electrical Purposes (D 315 – 52),[5] for Asbestos Roving for Electrical Purposes (D 375 – 52),[5] and for Asbestos Lap (D 1061 – 54):[5]

Footnote a.—Change to read as follows:

The factor 0.86 is based upon a measured average of 14 per cent water of crystallization in chrysotile asbestos. The asbestos content will be in error to the extent that the weight loss of the asbestos differs from the 14 per cent average. When the asbestos contains carbonates which decompose on heating, the weight loss from the decomposition of the carbonates will be combined with the weight loss from the ignition of the cotton, and an excessive cotton content will be indicated. This may result in an erroneous classification of the material to a lower grade.

The presence of carbonates in the asbestos and the amount of carbon dioxide which will be liberated from these carbonates can be determined by the Knorr alkalimeter as described in the Proposed Method of Test for Cotton Content of Asbestos Textile Materials.[1] When carbonates are present, the asbestos content shall be determined by the combustion-tube method, with corrections for this CO_2 liberated as described in the Proposed Method.[1]

REPORT OF COMMITTEE D-14

ON

ADHESIVES*

Committee D-14 held two regular meetings during the year: the first at the Shoreham Hotel, Washington, D. C., on October 7 and 8, 1954, and the second at ASA Headquarters, New York City, on March 31 and April 1, 1955.

At the present time Committee D-14 consists of 129 members, of whom 48 are classified as producers, 57 as consumers, 21 as general interest members, and 3 as consulting members.

New chairmen of the following subcommittees have been appointed in accordance with the By-laws of the committee which call for a change of chairmen every two years:

Subcommittee I on Strength Tests, C. E. Britt.

Subcommittee III on Tests for Permanency, D. A. George.

Subcommittee V on Specifications, S. L. Adams.

Subcommittee VII on Research Problems, J. E. Rutzler, Jr.

In order to facilitate the operations of the committee, there have been established in Subcommittee II on Analytical Tests sections on Aqueous Adhesives and on Solvent Adhesives; the Section on Solids and Moisture Content has been abolished. Subcommittee VII on Research Problems now contains Sections on Fundamentals of Tack, and on Literature.

Recommendations Accepted by the Administrative Committee on Standards

Subsequent to the 1954 Annual Meeting, Committee D-14 presented to the Society through the Administrative Committee on Standards a new Tentative Method of Testing Cross-Lap Specimens for Tensile Properties of Adhesives (D 1344 - 54 T). The recommendation was accepted by the Standards Committee on September 1, 1954, and the new method appears in the 1954 Supplement to Book of ASTM Standards, Part 7.

New Tentatives

The committee recommends that the following methods be accepted for publication as tentative as appended hereto:[1]

Method of Test for:

Susceptibility of Dry Adhesive Films to Attack by Roaches, and

Susceptibility of Dry Adhesive Films to Attack by Laboratory Rats.

Revisions of Tentatives

The committee recommends revisions of the following tentative methods:

Tentative Method of Test for Consistency of Adhesives (D 1084 – 50 T),[2] revised as appended hereto.[3]

Tentative Methods of Test for Resistance of Adhesives for Wood to Cyclic Accelerated Service Conditions (D 1183 - 51 T):[2]

Title.—Change to read: "Method of Test for Resistance of Adhesives for Wood to Cyclic Laboratory Aging Conditions."

Table I.—Change Procedure "A" to read as follows:

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* Presented at the Fifty-eighth Annual Meeting of the Society, June 26–July 1, 1955.

[1] The new tentatives appear in the 1955 Book of ASTM Standards, Part 7.

[2] 1952 Book of ASTM Standards, Part 7.

[3] The revised tentative appears in the 1955 Book of ASTM Standards, Part 7.

Name	Period, hr	Temperature		Relative humidity, per cent
		deg Cent	deg Fahr	
Interior	24	23 ± 1.1	73.4 ± 2	85 to 90
	24	48.5 ± 3	120 ± 5	<25
	72	23 ± 1.1	73.4 ± 2	85 to 90
	48	48.5 ± 3	120 ± 5	<25

Tentative Revision of Standard

The committee recommends that the following definitions of terms be published as tentative for addition to the Standard Definitions of Terms Relating to Adhesives (**D 907 – 52**):[2]

Viscosity.—The internal frictional resistance of an adhesive to flow when that resistance is directly proportional to the applied force.

Note.—Viscosity and consistency are erroneously used interchangeably. (See also Viscosity Coefficient and Consistency.)

Viscosity Coefficient.—The shearing stress tangentially applied which will induce a velocity gradient. A material has a viscosity of one poise when a shearing stress of one dyne per sq cm produces a velocity gradient of $\frac{1 \text{ cm per sec}}{\text{sec}}$. (See Viscosity.)

A-Stage.—An early stage in the reaction of certain thermosetting resins in which the material is fusible and still soluble in certain liquids. Sometimes referred to as Resol. (See B-Stage and C-Stage.)

B-Stage.—An intermediate stage in the reaction of certain thermosetting resins in which the material softens when heated and swells when in contact with certain liquids, but may not entirely fuse or dissolve. The resin in an uncured thermosetting adhesive, is usually in this stage. Sometimes referred to as Resitol. (See A-Stage and C-Stage.)

C-Stage.—The final stage in the reaction of certain thermosetting resins in which the material is relatively insoluble and infusible. Certain thermosetting resins in a fully cured adhesive layer are in this stage. Sometimes referred to as Resite. (See A-Stage and B-Stage.)

Resol.—An alternate term for A-Stage. (See A-Stage.)

Resitol.—An alternate term for B-Stage. (See B-Stage.)

Resite.—An alternate term for C-Stage. (See C-Stage.)

Bond Strength.—The unit load applied in tension, compression, flexure, peel, impact, cleavage, or shear, required to break an adhesive assembly with failure occurring in or near the plane of the bond.

Note.—The term adherence is frequently used in place of bond strength. (See also Adhesion and Bond.)

Bond, n.—The union of materials by adhesives.

Bond, v.—To unite materials by means of an adhesive. (See also Adhere.)

Resin, n.—A solid, semisolid, or pseudosolid organic material which has an indefinite and often high molecular weight, exhibits a tendency to flow when subjected to stress, usually has a softening or melting range, and usually fractures conchoidally.

Note. *Liquid resin.*—An organic polymeric liquid which when converted to its final state for use becomes a resin.

Adoption of Tentatives as Standard Without Revision

The committee recommends that the following tentatives be approved for reference to letter ballot of the Society for adoption as standard without change:

Method of Test for:

Effect of Bacterial Contamination on Permanence of Adhesive Preparations and Adhesive Bonds (**D 1174 – 51 T**),[2] and

Strength of Adhesives on Flexural Loading (**D 1184 – 51 T**).[2]

Adoption of Tentative Revisions of Standard

The committee recommends the adoption as standard definitions of the following terms which have appeared as tentative revisions of the Standard Definitions of Terms Relating to Adhesives (**D 907 – 52**):[2] doctor roll, permanence, pickup roll, syneresis, thixotropy, warp (n.), yield value, plasticity, primer, plywood, wood built-up laminated, and wood glued laminated.

Tentatives Continued Without Revision

The committee recommends that the following tentatives be continued without revision pending the results of further study:

Recommended Practice for:

Determining the Effect of Artificial (Carbon-

Arc Type) and Natural Light on Permanence of Adhesives (**D 904 – 46 T**),
Determining Strength Development of Adhesive Bonds (**D 1144 – 51 T**),

Method of Test for:

Strength Properties of Adhesives in Shear by Tension Loading (Metal-to-Metal) (**D 1002 – 53 T**),
Consistency of Adhesives (Method A) (**D 1084 – 50 T**), and
Effect of Mold Contamination on Permanence of Adhesive Preparations and Adhesive Bonds (**D 1286 – 53 T**).

REAPPROVAL OF STANDARDS

The committee recommends that the following standards, which have stood for six years, be continued without revision:

Method of Test for:

Tensile Properties of Adhesives (**D 897 – 49**),
Peel or Stripping Strength of Adhesives (**D 903 – 49**),
Strength Properties of Adhesives in Shear by Compression Loading (**D 905 – 49**), and
Strength Properties of Adhesives in Plywood Type Construction in Shear by Tension Loading (**D 906 – 49**).

EDITORIAL CHANGE

The committee recommends that the title of the Recommended Practice for Determining the Effect of Moisture and Temperature on Adhesive Bonds (**D 1151 – 51 T**)[2] be editorially revised to read "Method for Determining the Effect of Moisture and Temperature on Adhesive Bonds."

The recommendations in this report have been submitted to letter ballot of the committee, the results of which will be reported at the Annual Meeting.[4]

ACTIVITIES OF SUBCOMMITTEES

Subcommittee I on Strength Tests (C. E. Britt, chairman).—Work is continuing on the proper rate of loading to be employed in the Method of Test for Strength Properties of Adhesives in Shear by Tension Loading (Metal-to-Metal) (D 1002 – 53 T). There is renewed interest in peel strength testing, and a survey of existing methods is under way. The use of butt-joint specimens for evaluating tensile, cleavage, and impact strengths is of continuing interest. The importance of creep and cold flow testing to the building trades is recognized.

Subcommittee II on Analytical Tests (G. F. Lipsey, chairman).—The main activity for the past few years has been the development of a solids content test for urea resin adhesives. This method has now been submitted to subcommittee ballot. A survey of Committee D-14 needs for analytical methods indicates that the work of developing standards could best be carried on by establishing sections on aqueous and solvent adhesives. Proposed methods for nonvolatile content, pH, filler content, and amylaceous content of adhesives will be circulated for subcommittee comments.

Subcommittee III on Tests for Permanency (D. A. George, chairman).—A collaborative testing program is under way for other than wood adhesives using the revised Methods of Test for Resistance of Adhesives for Wood to Cyclic Accelerated Service Conditions (D 1183 – 51 T). The subcommittee has as one of its main interests the establishment of short-term laboratory tests which will correlate with long-term use experiences. Methods of obtaining long-term use data are being discussed. Tests will be made during the coming year to study the soaking cycle in the Recommended Practice for Determining the Effect of Moisture and Temperature on Adhesive Bonds (D 1151 – 51 T). The problems of high-temperature service and marine and chemical exposure are being considered.

Subcommittee IV on Working Qualities (M. Petronio, chairman).—Two new methods of measuring consistency are referred to previously in this report for publication as tentative. Work is continuing on the measurement of tack by two different instruments. Critical glue line thickness has been studied, and slippage and flow (of cured bonds) has been a subject of discussion.

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[4] The letter ballot vote on these recommendations was favorable; the results of the vote are on record at ASTM Headquarters.

Subcommittee V on Specifications (S. L. Adams, chairman).—A skeletal specification for sealing the top flaps of fiberboard shipping cartons was prepared and distributed. Completion of the specification depends upon development of suitable test methods for bonding permanency, initial tack, and setting time. A preliminary draft for bonding permanency has been prepared. A test procedure for the determination of solids of packaging adhesives has been prepared and submitted to limited collaborative testing.

A tentative procedure for determining the effect of temperature and moisture on label-to-glass adhesive bonds has been prepared and circulated.

Specifications for high-temperature setting resin adhesives and for room temperature and intermediate temperature adhesives are being submitted for letter ballot.

Subcommittee VI on Nomenclature and Definitions (F. W. Reinhart, chairman).—New definitions and revisions of certain terms have been the subject of subcommittee and committee discussions and ballots. Twelve definitions of terms are recommended as standard additions to D 907 - 52, and twelve additional terms are being recommended as tentative revisions.

Subcommittee VII on Research (J. E. Rutzler, Jr., chairman).—A talk by A. A. Marra, entitled "An Analysis of a Wood Adhesive Test Method Using a Cross-Lap Specimen," constituted the main portion of the program of the fall meeting. The subcommittee was assigned the dual task of studying the fundamental meaning of "tack" and of measurements of tack and preparing semi-annual bibliographies of the literature of adhesives. A round-table discussion of "tack" and its measurement was presented at the spring meeting, based on a report issued by the subcommittee. G. W. Koehn, L. M. Perry, F. W. Reinhart, A. E. Reynolds, and J. E. Rutzler, Jr., participated. Sections on "Literature of Adhesives" and "Fundamentals of Tack" were created. Other fundamental problems will be studied as specific interests are manifested.

This report has been submitted to letter ballot of the committee, which consists of 105 voting members; 77 members returned their ballots, of whom 65 have voted affirmatively and 0 negatively.

Respectfully submitted on behalf of the committee,

R. F. Blomquist,
Chairman.

C. K. M. Winne,
Secretary.

REPORT OF COMMITTEE D-15

ON

ENGINE ANTIFREEZES*

Committee D-15 on Engine Antifreezes held two meetings during the year: in New York City on October 15, 1954, and in Washington, D. C., on March 23 to 25, 1955. The Advisory Committee and subcommittees met concurrently.

There have been three resignations and two additions to the list of committee members during the year. At present the committee is composed of 35 voting members, of whom 18 are classified as producers, 7 as consumers, and 10 as general interest members.

The one change in subcommittee chairmanship occurring during the year was the appointment of F. G. Church to succeed N. W. Faust as chairman of Subcommittee II on Antifreeze Field Testers.

NEW TENTATIVE

Committee D-15 recommends that the Method for Glassware Corrosion Test for Engine Antifreezes be accepted for publication as tentative as appended hereto.[1]

TENTATIVES CONTINUED WITHOUT REVISION

Committee D-15 recommends that the following tentative specification and methods be continued as tentative without change:

Tentative Specification for:

Hydrometer Thermometer Field Tester for Engine Antifreezes (**D 1124 - 53 T**),

Tentative Methods of Test for:

Ash Content of Concentrated Engine Antifreezes (**D 1119 - 53 T**), and

pH of Concentrated Engine Antifreezes (**D 1287 - 53 T**).

The recommendations in this report have been submitted to letter ballot of the committee, the results of which will be reported at the Annual Meeting.[2]

ACTIVITIES OF SUBCOMMITTEES

Subcommittee II on Antifreeze Field Testers (F. G. Church, chairman) is revising Specification D 1124 - 53 T, Hydrometer Thermometer Field Tester for Engine Antifreezes, to include a test method for obtaining basic data with hydrometers for the initial calibration of these testers. A Study Group on Direct Reading Testers (J. J. Ondrejcin, chairman) is investigating other than hydrometer-thermometer type testers such as the direct freeze type in which a sample of the antifreeze is frozen with dry ice or CO_2 gas.

Subcommittee IV on Chemical Properties (E. G. Travis, chairman).—The Tentative Method of Test for Ash Content of Concentrated Antifreezes (D 1119 - 53 T) and the Tentative Method for

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*** Presented at the Fifty-eighth Annual Meeting of the Society, June 26–July 1, 1955.**

[1] The new tentative appears in the 1955 Book of ASTM Standards, Part 5.

[2] The letter ballot vote on these recommendations was favorable; the results of the vote are on record at ASTM Headquarters.

pH of Concentrated Antifreezes (D 1287 - 53 T) were reviewed and recommended for continuation as tentative.

Recent developments in ASTM Committee D-1 on Paints have indicated a change in the solvents specified when determining water in organic solvents by the Karl Fischer Reagent Method is desirable. The desirability of a similar change in Method of Test for Water in Concentrated Engine Antifreezes by the Iodine Reagent Method (D 1123 - 54) is under investigation.

Subcommittee V on Effects of Antifreeze on Rubber Hose (O. W. Chandler, chairman).—A fourth series of collaborative tests on a proposed test method to determine the effects of engine antifreezes on rubber cooling system hoses was completed. In these tests, 14 commercial antifreezes and distilled water were tested in 12 laboratories. The data from these tests have not been completely analyzed; however, it appears that the test method under evaluation will prove satisfactory as a laboratory test for giving relative effects of antifreezes on rubber hoses.

Subcommittee VI on Simulated and Actual Service Testing (C. H. Sweatt, chairman) has accepted the latest recommendations of its study group concerning modification in the 336-hr corrosion test procedure. This culminates several years of cooperative work on the glassware corrosion test. An outline of the development of this procedure and its limitations is appended to this method.

The original study group was authorized to initiate work on a glassware foaming test, while a newly appointed panel undertakes the development of a service simulation type of corrosion test.

During the past year, the Study Group on Test Methods (C. H. Sweatt, chairman) has worked out additional details of the glassware corrosion test and has conducted a collaborative program to evaluate methods of controlling evaporation losses with low-boiling antifreezes. Under the new title of Study Group on Glassware Test Methods, this panel will initiate work on a laboratory foaming test for engine antifreezes.

This report has been submitted to letter ballot of the committee, which consists of 35 voting members; 32 members returned their ballots, of whom 31 have voted affirmatively and 0 negatively.

Respectfully submitted on behalf of the committee,

H. R. WOLF,
Chairman.

C. F. GRAHAM,
Secretary.

REPORT OF COMMITTEE D-16
ON
INDUSTRIAL AROMATIC HYDROCARBONS AND RELATED MATERIALS*

Committee D-16 on Industrial Aromatic Hydrocarbons and Related Materials and its subcommittees held meetings on June 14 and 15, 1954, in Chicago, Ill., and on February 21 and 22, 1955, at Roanoke, Va.

The committee has elected 12 new members.

New subcommittees were formed on Statistical Procedure (W. J. Tancig, chairman) and on Thermometers (K. H. Ferber, chairman). The Subcommittee on Nomenclature and the Editorial Subcommittee have been combined under the chairmanship of E. T. Scafe.

REVISION OF STANDARD, IMMEDIATE ADOPTION

The committee recommends for immediate adoption the following revisions of the Standard Method of Test for Distillation of Industrial Aromatic Hydrocarbons (**D 850 – 50**),[1] and accordingly asks for the necessary nine-tenths affirmative vote at the Annual Meeting in order that the revisions may be submitted to letter ballot of the Society:

Section 2(*b*)(*2*).—Change the following dimensions for thermometers to read as follows:

Total length	318 to 322 mm.
Length of bulb	15 to 20 mm.
Contraction chamber:	
Top of chamber to bottom of bulb	35 mm, max.
Distance from bottom of bulb to graduation line at:	
70 C, for thermometer range of 70 to 120 C	90 to 110 mm.
110 C, for thermometer range of 110 to 160 C	90 to 110 mm.

Delete the last two sentences.

REAPPROVAL OF STANDARDS

The committee recommends the reapproval of the following standards, including an editorial change in the title of Method D 852 – 47 to read as shown:

Method of Test for:

Acidity of Benzene, Toluene, Xylenes, and Similar Industrial Aromatic Hydrocarbons (**D 847 – 47**),

Acid Wash Color of Benzene, Toluene, Xylenes, Refined Solvent Naphthas, and Similar Industrial Aromatic Hydrocarbons (**D 848 – 47**),

Copper Corrosion of Industrial Aromatic Hydrocarbons (**D 849 – 47**),

Paraffins in Industrial Aromatic Hydrocarbons (**D 851 – 47**),

Solidification Point of Benzene (**D 852 – 47**), and

Color and Hydrogen Sulfide and Sulfur Dioxide Content (Qualitative) of Industrial Aromatic Hydrocarbons (**D 853 – 47**).

The recommendations appearing in this report have been submitted to letter ballot of the committee, the results of which will be reported at the Annual Meeting.[2]

ACTIVITIES OF SUBCOMMITTEES

Subcommittee A on Monocyclic Aromatics (S. S. Kurtz, Jr., chairman).—The following items are active:

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* Presented at the Fifty-eighth Annual Meeting of the Society, June 26–July 1, 1955.

[1] 1952 Book of ASTM Standards, Part 5.

[2] The letter ballot vote on these recommendations was favorable; the results of the vote are on record at ASTM Headquarters.

1. Bromine index determination by potentiometric titration. A method of test has been published as information, and the subject is under further study.

2. Development of spectroscopic methods for determining isomer distribution in nitration grade xylene.

3. A method for the determination of thiophene.

4. Formulation of specifications for benzene, toluene, and xylenes acceptable to both Committee D-1 on Paint, Varnish, Lacquer, and Related Products, and Committee D-16.

5. The development of temperature correction tables for benzene, toluene, and xylenes.

Subcommittee B on Polycyclic Aromatics (M. Mitchell, chairman).—With the aim of reaching agreement on methods for refined naphthalene, six samples of naphthalene were cooperatively tested by seven companies. Test points covered were solidification point, acid wash test, color, and ash.

Subcommittee C on Phenolic Compounds (V. S. Morello, chairman).—In order to evaluate proposed methods, cooperative tests were made by five member laboratories on phenol samples from four different production processes. Test points covered were solidification point, water content, and water solubility. The use of molecular sieve drying prior to solidification point determination accomplished reproducible results.

Subcommittee D on Nitrogen Heterocyclics (W. E. Sisco, chairman).—Methods for testing pyridine and quinoline have been circulated for study and some revisions have been made. Cooperative test work will be done on pyridine for oil content and permanganate stability.

This report has been submitted to letter ballot of the committee which consists of 54 members; 36 members returned their ballots, all of whom have voted affirmatively.

Respectfully submitted on behalf of the committee,

D. F. GOULD,
Chairman.

F. J. POWELL,
Secretary.

REPORT OF COMMITTEE D-17

ON

NAVAL STORES*

Committee D-17 on Naval Stores held one meeting during the year: on June 16, 1954, at Chicago, Ill., in connection with the 1954 Annual Meeting of the Society.

The committee regrets the loss of one member by death, K. A. Horn, representing Congoleum-Nairn, Inc. One new company member in the producer category was added, General Mills, Inc., processors of tall oil and the rosin acids and fatty acids contained therein.

At its meeting G. J. Chamberlin, Technical Director of Tintometer, Ltd., Salisbury, England, manufacturers of the well-known Lovibond colorimeter glasses, described some of the improvements that had been made during the past few years in the manufacture of this glass, which permitted the continuation of the cooperative work with the U. S. Department of Agriculture in the development of rosin standards from the English glass, as discussed in the 1954 Annual Report of the committee. Such Lovibond rosin standards are now available, having the same general form, appearance, and color composition as the U. S. Official Rosin Standards issued on loan by the Department of Agriculture. They can be obtained through the American agent of the British firm, with certification of color agreement by the Department of Agriculture, if desired.

RECOMMENDATION ACCEPTED BY THE ADMINISTRATIVE COMMITTEE ON STANDARDS

Subsequent to the 1954 Annual Meeting, Committee D-17 presented to the Society through the Administrative Committee on Standards the recommendation for revision of the Tentative Methods of Test for Unsaponifiable Matter in Rosin (**D 1065 – 51 T**) to include an alternate separatory funnel method of extracting unsaponifiables from the saponification liquor. This recommendation was accepted by the Standards Committee on November 5, 1954, and the revised methods appear in the 1954 Supplement to Book of ASTM Standards, Part 4.

PROPOSED METHODS TO BE PUBLISHED AS INFORMATION

The committee recommends that the following two proposed methods be published as information only as appended hereto:[1]

Method of Test for Crystallization Tendency of Gum Rosin, and
Methods of Testing Tall Oil Skimmings.

REVISION OF STANDARD, IMMEDIATE ADOPTION

The committee recommends for immediate adoption the following revisions of the Standard Methods of Sampling and Grading Rosin (**D 509 – 52**),[2] and accordingly asks for the necessary nine-tenths affirmative vote at the Annual Meeting in order that the revisions may be referred to letter ballot of the Society. The revision is recommended in view of the complete disappearance of wooden barrels as containers of rosin, and the availability of standards for grading rosin, made in England from Lovibond glass, which can now be had with a Federal Certificate of Conformity with the U. S. Official Rosin Standards, heretofore available only on loan from the U. S. Department of Agriculture.

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* Presented at the Fifty-eighth Annual Meeting of the Society, June 26–July 1, 1955.

[1] See pp. 531 and 533.

[2] 1952 Book of ASTM Standards, Part 4.

Section 2.—Change Paragraph (*c*) to read as follows:

(*c*) *Heating device.*—An electrically heated device for shaping and smoothing the surfaces of the sample to the required dimension for grading ($\frac{7}{8}$ in. thick in the viewing direction). The device shown (*E*, Fig. 1) was constructed from a 3-in. length of $1\frac{1}{2}$-in. copper T-bar, $\frac{1}{4}$ in. thick, which was nickel-plated. One section or fin, opposite those forming the 90 deg polished faces, is clamped between two heating elements. The temperature must be regulated by means of a variable voltage transformer, to prevent overheating and too rapid melting or scorching of the sample faces. An electric flat iron, mounted in a nearly vertical position, point down, with similar heat control, also serves the purpose.

Replace the first three sentences of Paragraph (*e*) with the following:

(*e*) The official standards for use in grading rosin (*G*, Fig. 1) consist of assemblies of colored glass slides, cemented together, as issued on loan by the U. S. Department of Agriculture, or the similar combinations of Lovibond glasses that have been certified by the Department, for use in grading. The grades and standards are designated as follows: X, WW, WG, N, M, K, I, H, G, F, E, D. A special grade, FF, is used for dark wood rosins. The standards issued by the Department of Agriculture (except FF) consist of combinations of plates cut, ground, and polished to specified thicknesses from selected melts of Corning and Jena colored glass.

Change Paragraph (*f*) to read as follows:

(*f*) Secondary standards or "type samples" are sometimes used for approximate grading, in the absence of permanent official standards of glass. Such samples may consist of cubes of specially selected rosin or other colored transparent medium; solutions are also sometimes used (Note). Secondary standards or "types" are usually not permanent in color and must be protected from excessive exposure to sunlight or heat. Wrapping and storage in a cool dark place when not in use is recommended. To insure correctness of grading therewith, they should be tested periodically by comparison with permanent glass standards.

Section 3(b).—Replace the first two sentences with the following:

(*b*) After removing the friction cap from the filler opening in the top of the drum, spike into the rosin and remove enough broken material to permit access to the rosin several inches below the surface. Then spike out a solid lump as large as possible (*H*, Fig. 1) from which an approximate $\frac{7}{8}$-in. cube can be cut. No part of the lump should have been less than 2 in. below the original surface.

TENTATIVE REVISION OF STANDARDS

The committee recommends the following revision of the definitions for "Dipentene," "Monocyclic Terpenes," and "Rosin Standards" be published as tentative revisions of the Standard Definitions of Terms Relating to Naval Stores and Related Products (**D 804 – 52**):[2]

Dipentene.—The optically inactive form of the monocyclic terpene hydrocarbon limonene. Commercial dipentenes contain substantial portions of other monocyclic and bicyclic, as well as some oxygenated terpenes having closely related boiling ranges. They are generally obtained by fractional distillation from the crude oils recovered in the several commercial methods of utilizing pine wood, also by isomerization during the chemical processing of terpenes. The four kinds of commercial dipentene are:

1. *Steam distilled dipentene,* from the crude oleoresinous extract used for the processing of related steam distilled wood naval stores.
2. *Sulfate dipentene,* from the crude condensate of the vapors generated in the digestion of wood in the sulfate paper pulp process.
3. *Destructively distilled dipentene,* from the

lighter portions of the oil recovered during the destructive distillation of pine wood.

4. *Chemically processed dipentene*, recovered as a by-product in connection with the chemical treatment and conversion of other terpenes.

NOTE.—There is no legal requirement under the Naval Stores Act that the source, origin, or kind of dipentene be shown in the commercial designation. Consequently, coined trade names are sometimes used in selling this product.

Monocyclic Terpenes.—A designation sometimes used in the trade to describe a heterogeneous mixture of monocyclic, bicyclic and other related terpene hydrocarbons recovered or removed in the fractionation of certain terpenes or other essential oils, or as a by-product in the chemical conversion of pinenes; generally sold under trade names. (The term "other monocyclic hydrocarbons," used in statistical reports of the U. S. Department of Agriculture, covers this type of material.)

Rosin Standards.—The combinations of assembled colored glasses having the colors designated as representative of the established U. S. grades used in classifying rosin. The recognized official standards are those developed and issued by the U. S. Department of Agriculture, or similar standards made of Lovibond glass, when certified by the same Government agency. The official grades established by or under authority of the Federal Naval Stores Act, for which standards are provided, are as follows: X, WW, WG, N, M, K, I, H, G, F, E, D, and FF (the latter grade is used only for wood rosin).

REAPPROVAL OF STANDARDS

The committee recommends that the following methods be reapproved as standard:

Methods of Sampling and Testing:

Dipentene (**D 801 - 48**),
Pine Oil (**D 802 - 49**),
Pine Tars and Pine-Tar Oils (**D 856 - 49**).

The recommendations in this report have been submitted to letter ballot of the committee, the results of which will be reported at the Annual Meeting.[3]

ACTIVITIES OF SUBCOMMITTEES

Subcommittee I on Softening Point of Rosin (J. M. Schantz, chairman) has taken no action as yet on the consolidation of the two ASTM Ball and Ring Softening Point Methods E 28 - 51 T and D 36 - 26. Tests were made of a sinking mercury method that was included in a recently proposed Indian specification for softening point of rosin, the details of which were described at the last annual meeting of the committee. The method did not give sufficiently concordant and duplicable results that would seem to warrant further collaborative testing, particularly in view of the hazards involved in any method in which large quantities of mercury are subjected to heating in the open air. Inquiry among committee members also failed to reveal any laboratories equipped with the Dennis-Parr electrically-heated softening point bar, to permit committee testing therewith.

Subcommittee II on Crystallization of Rosin (S. R. Snider, chairman) has conducted numerous tests on the crystallization of samples of gum rosin representing rosin from different points in the gum naval stores producing area and made at different times during the season. As the result of these studies, a proposed method of test for determining the crystallizing tendency of gum rosin has been prepared and is referred to previously in this report for publication as information. This initial study was limited to gum rosin because it was found that the crystallizing tendency of all the wood rosins and tall oil rosins tested was too great to permit any sharp differentiation or evaluation by the test used.

Subcommittee IV on Chemical Analysis of Rosin (R. Herrlinger, chairman).—The collaborative work of the subcommittee proved the need for greater concentration of the alkali solution used in the Method of Test for Unsaponifiable Matter in Rosin (D 1065 - 51 T), in order to saponify rosin esters. The alkali was increased from 0.5 N to approximately 2 N dissolved in 85 per cent ethanol. With this change, and several others involving manipulation and handling of solutions, it was found that good agreement was obtainable by both the existing tentative continuous extraction method and the alternate method that had been under study using separatory funnels for extraction of the unsaponifiables. The latter method had been regularly used for unsaponifiables in tall oil. On the basis of the good agreement among collaborators, with the two methods as revised, using gum, wood, and tall oil rosins, the committee recommended the addition of the separatory funnel method to the existing tentative. The revision was accepted by the Administrative Committee on Standards. Consideration is being given to the standardization of other test methods applicable to rosin, such as optical rotation, identification of rosin acid components, and hardness or penetration.

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[3] The letter ballot vote on these recommendations was favorable; the results of the vote are on record at ASTM Headquarters.

Subcommittee V on Tall Oil (A. Pollak, chairman).—On the basis of collaborative work, it appears desirable to make a number of revisions in the Standard Methods of Testing Tall Oil (D 803 – 51). These changes will include an extension of the time for esterification of fatty acids from 2 min to 30 min, in the referee and Modified Wolff Method of determining rosin acids; a direct computation of rosin acids without the use of a rosin acid number; elimination of the correction number now included in the McNichol method for determining rosin acids; revision of the unsaponifiable method to bring it into conformity with the funnel method as now given in Methods D 1065 – 54 T. These revisions of Methods D 803 and other revisions of an editorial nature are now being prepared and will be submitted for consideration by the main committee in the near future. Such changes should make the method more suitable for refined tall oils having relatively low rosin acid content.

A proposed method has been prepared for testing and evaluating tall oil skimmings, the crude product of the paper pulp process from which whole tall oil is recovered by acidulation. This method is appended to this report, as information only.

Subcommittee VII on Terpene Hydrocarbons and Pine Oil (R. E. Price, chairman).—Developments in Committees D-1 and D-2 on the choice of a larger distillation flask, namely, a 200-ml instead of a 100-ml size, for paint vehicle thinners, are being given careful consideration in view of the fact that the recommendation for the use of the larger flask has originated in Subcommittee V of Committee D-1, which had initial jurisdiction over the turpentine test methods (D 233 – 51). Tests in this subcommittee to date have indicated that the 100-ml flask is of ample size for carrying out the distillation test on turpentine, dipentene, and other terpene oils and that no advantage would be had by substitution of the 200-ml flask in the distillation test for terpene oils.

Subcommittee IX on Definitions (J. L. Boyer, chairman).—A revised and expanded definition for dipentene has been prepared, which will serve to differentiate between the different kinds of dipentene according to the particular source or method of production. The definition for "rosin standard" has been revised to give recognition to the standards made from Lovibond glass, after these have been tested and certified by the U. S. Department of Agriculture. A definition for the trade term "monocyclic terpenes" is offered, since such a classification is used in Government statistical reports.

Subcommittee X on Specifications (S. R. Snider, chairman).—Although no reportable activity on the preparation of specifications has been carried on, the chairman has continued to compile information on this subject, particularly on the needs and the benefits to the naval stores industry and consumers from ASTM Specifications for naval stores products, other than turpentine.

This report has been submitted to letter ballot of the committee, which consists of 37 voting members; 25 members returned their ballots, of whom 23 have voted affirmatively and 0 negatively.

Respectfully submitted on behalf of the committee,

V. E. GROTLISCH,
Chairman.

W. A. KIRKLIN,
Secretary.

EDITORIAL NOTE

Subsequent to the Annual Meeting, Committee D-17 presented to the Society through the Administrative Committee on Standards the recommendation that the Standard Methods of Testing Tall Oil (D 803 - 51) be revised and reverted to tentative status. This recommendation was accepted by the Standards Committee on September 15, 1955, and the revised methods appear in the 1955 Book of ASTM Standards, Part 4.

APPENDIX I

PROPOSED METHOD OF TEST FOR CRYSTALLIZATION TENDENCY OF GUM ROSIN[1, 2]

This is a proposed method and is published as information only. Comments are solicited and should be addressed to the American Society for Testing Materials, 1916 Race St., Philadelphia 3, Pa.

Scope

1. This method of test is designed for determining the crystallization tendency of gum rosin. It is published for use in connection with further crystallization studies on rosin. The method is not suitable for use on wood rosin or tall oil rosin.

Significance of Test

2. The detailed requirements of this method represent the optimum conditions under which the test may be performed. The results may provide an arbitrary index for comparing the relative crystallization tendencies of gum rosins, for the purpose of ascertaining the suitability of a gum rosin for the industrial production of certain compounds or products, where crystallization in the ultimate product would be an objectionable characteristic.

Apparatus

3. (*a*) *Flask.*—A 250-ml wide mouth Erlenmeyer flask, preferably with 34/45 standard-taper joint (with 34/45 to 24/40 reducing adapter) to facilitate introducing rosin into the flask; fitted with 34/45 standard-taper stopper; made of heat-resistant glass.

(*b*) *Condenser, Water-Jacketed,* with 24/40 standard-taper joint, with jacket at least 12 in. in length, made of heat-resistant glass.

(*c*) *Electric Heater,* of the hot-plate type, with adjustable heat control.

(*d*) *Support for Condenser.*—Any suitable tripod or stand with clamps for holding condenser.

(*e*) *Mortar and Pestle,* of vitreous chemical porcelain.

Reagents

4. (*a*) *Acetone,* cp.

(*b*) *Rosin Acid Crystals.*—For use in seeding, crystals of rosin acid, such as abietic acid and its isomers, may be conveniently prepared by dissolving 5 g of a pale wood rosin in 15 ml of acetone and allowing the solution to stand in an unstoppered flask for 24 hr or more to permit slow evaporation of the solvent. (Pure abietic acid crystals are not necessary.) The separated crystals are then filtered onto a coarse filter paper and washed with a little ethyl alcohol (Formula 30 or 3 A of the U. S. Bureau of Internal Revenue). The paper and crystals should be dried in an oven at about 100 C, transferred to a vacuum

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[1] This proposed method is under the jurisdiction of the ASTM Committee D-17 on Naval Stores.

[2] Published as information, June, 1955.

desiccator, and cooled under reduced pressure. Store the crystals in a small vial for future use.

Procedure

5. (*a*) Cut away the outer shell of a solid lump of the rosin under test (to avoid the inclusion of any oxidized rosin) and grind about 15 g of the fresh rosin pieces to a coarse powder, in a mortar. Weigh 10.0 ± 0.1 g of the ground sample and transfer to the Erlenmeyer flask. Add 5 ml acetone from a pipet or graduated cylinder, stopper, and swirl the flask to wet the powder.

(*b*) Exchange the adapter for the stopper, connect to the condenser, and warm on a hot plate. Regulate the heat so that the reflux rate of the condensed solvent is about 5 to 10 drops per sec, and boil gently for 30 min. Swirl the flask occasionally to insure complete solution of all particles of rosin.

(*c*) Disconnect the flask, stopper, and set aside to cool to room temperature (do not use tap water).

(*d*) Seed the cold solution in the flask with a freshly broken fragment (about 10 mg) of a rosin acid crystal, so that contact will be made with a crystalline surface. Restopper and observe hourly for any indication of crystals and record observations. If the seed dissolves, another must be added until the seed survives. Occasionally swirling of the flask usually accelerates crystal formation.

Report

6. Rosins shall be reported as falling in one of the following crystallization groups:

Group 1.—Rosins showing no evidence of crystals in seven days; crystallization is not likely to occur even if observation period is extended to 30 or 60 days.

Group 2.—Rosins yielding only a few sparsely scattered and separated fine crystals, after six to seven days standing. The number of crystals in this group will not increase appreciably even on prolonged standing.

Group 3.—Rosins showing indication of crystallization after standing overnight. In this group progressive crystallization occurs on prolonged standing, with scattered clusters of crystals, single crystals, or a mixture of both.

Group 4.—Rosins showing indication of crystals within 2 to 6 hr. Advanced crystallization occurs on standing overnight, and mass crystallization within 2 to 3 days.

APPENDIX

Experiments have shown that crystallization of the rosin acids in rosin is more readily accomplished from an acetone solution than in other organic solvents, or by any of the other procedures previously tried. Therefore, it appears reasonable to assume that a rosin that shows no crystallization tendency in acetone would not crystallize from any other solvent or by any other test; also that a rosin that readily crystallizes in mass might be expected to display the same behavior when used in certain industrial processes. Between these two extremes, the tendency of rosin to crystallize might be determined by reference to the time required and the nature and quantity of crystals formed in an acetone solution, under controlled conditions. On the basis of preliminary tests, the phenomenon of rosin crystallization might be evaluated by four groupings:

Group 1.—Rosins that show no tendency to crystallize and that would not be expected to do so under normal conditions,

Group 2.—Rosins that probably would not crystallize, but if so only to a negligible extent,

Group 3.—Rosins that might be expected to crystallize to an appreciable degree if the conditions were generally favorable, and

Group 4.—Rosins that would crystallize if crystallization is easily induced.

NOTE.—These observations are based on the condition that the molecular structure of the rosin acids is not altered ir the process of use.

APPENDIX II

PROPOSED METHODS OF TESTING TALL OIL SKIMMINGS[1, 2]

These are proposed methods and are published as information only. Comments are solicited and should be addressed to the American Society for Testing Materials, 1916 Race St., Philadelphia 3, Pa.

Scope

1. (*a*) These methods cover procedures for testing tall oil skimmings for the purpose of establishing its composition in terms of only those components which are considered of chief interest to skimmings producers and consumers.

(*b*) The following tests are covered:

	Sections
Apparent density	3 to 5
Total solids	6 to 9
Tall oil yield	10 to 13
Saponification Number	14
Black liquor solids	15

Sampling

2. (*a*) If an appreciable amount of drainable black liquor is associated with the skimmings, it should be drained off and measured before sampling. In tanks and tank cars this may be most easily done by measuring the volume before and after draining. The density of the black liquor is then measured and the weight drained is calculated. In small samples the weight of drained black liquor can be established by direct weighing before and after draining.

(*b*) The representative sampling of the drained skimmings is difficult where large quantities are involved. In the case of tank car shipments a convenient procedure is to withdraw samples from the pump line continuously or at selected intervals during pumping. If continuous samples are withdrawn, care should be taken that there is no tendency to strain the skimmings from the occluded black liquor at the sampling valve. In the case of tanks, the problem is more difficult if the tank is not be be emptied at the time of sampling. If the tank contents can be recirculated, however, samples can be withdrawn continuously or at intervals from the recirculating line. Small quantities of skimmings can be sampled reasonably well by agitating the whole quantity thoroughly before withdrawing the sample.

APPARENT DENSITY

Apparatus

3. (*a*) *Container*.—A cylindrical vessel with straight sides and smooth top and of a capacity of about 1 gal, with a height approximating its diameter. A stainless steel pot or a stainless steel 4000-ml beaker without a spout is satisfactory.

(*b*) *Scale*.—A scale accurate to ±0.01 lb.

Procedure

4. (*a*) Establish the volume of the vessel by weighing it empty and then full to the brim with water at 68 F. The volume of the vessel in gallons is the weight of water in pounds divided by the

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[1] These proposed methods are under the jurisdiction of the ASTM Committee D-17 on Naval Stores.

[2] Published as information, June, 1955.

density of water in pounds per gallon, (8.32 lb per gal).

(*b*) Fill the vessel with the sample and adjust the level to the brim by passing a flat steel blade across the top. Weigh the vessel and its contents and deduct the tare. The apparent density of the skimmings is the weight of the skimmings divided by the volume.

Report

5. Report the result to the nearest 0.01 lb and state the temperature of the skimmings.

TOTAL SOLIDS

Apparatus

6. The apparatus shall conform to the requirements for the moisture apparatus described in Section 14 of the Methods of Testing Tall Oil (ASTM Designation D 803).[3] A 500-ml flask shall be used.

Reagent

7. *Xylene, cp.*

Procedure

8. Transfer 10.00 g of the sample to the 500-ml flask and proceed as directed in Section 16 of Methods D 803.

Calculation and Report

9. (*a*) Calculate the percentage of total solids as follows:

$$\text{Total solids, per cent} = (10.00 - W) \times 10$$

where W = milliliters of water measured.

(*b*) Report the percentage of total solids to the nearest whole number.

TALL OIL YIELD

Apparatus

10. *Separatory Funnels*, 500-ml.

Reagents

11. (*a*) *Diethyl Ether.*

(*b*) *Hydrochloric Acid (sp gr 1.18 to 1.19).*

(*c*) *Methyl Orange Indicator Solution.*

(*d*) *Sodium Chloride Solution 50 g NaCl per liter).*

Procedure

12. (*a*) Transfer approximately 5 g of the sample, weighed to nearest 0.01 g from a weighing bottle, to a 500-ml separatory funnel. Add 50 ml of ether and 50 ml of NaCl solution, previously shaken together. Shake until the skimmings are dissolved.

(*b*) Add 1 or 2 drops of methyl orange indicator solution; then add HCl dropwide to a slight excess and shake thoroughly. If the solution does not remain pink, add more HCl until the indicator stays pink after shaking. Allow to stand about 30 min.

(*c*) In a second separatory funnel shake 50 ml of ether with 10 ml of NaCl solution. Drain the aqueous bottom layer of the first funnel into the second funnel. Shake, let stand, and drain off the bottom layer into another funnel. Repeat four or five times until the ether extract is colorless. Combine the ether extracts (300 to 350 ml) and wash twice with 50 ml of water previously saturated with ether. Continue washing until the aqueous layer is neutral to methyl orange.

(*d*) Transfer about half of the washed ether extract to a tared 250-ml Erlenmeyer flask. Distill off the bulk of the ether on a steam bath through a cold water condenser, cool the flask, and add the rest of the ether extract. Again distill off the bulk of the ether and then evaporate the remaining extract until free from ether. Remove any residual water by adding about 10 to 20 ml of methanol and evaporating on a steam bath to constant weight. Save the extract for a saponification number determination.

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[3] 1952 Book of ASTM Standards, Part 4.

Calculation and Report

13. Calculate the weight of the dry extract as a percentage of the original sample of skimmings and report the result to one significant place after the decimal point. The result is the tall oil yield.

SAPONIFICATION NUMBER

Procedure

14. Determine the saponification number in accordance with Sections 36 to 40 of the Methods of Testing Tall Oil (ASTM Designation D 803).[3]

BLACK LIQUOR SOLIDS

Calculations

15. Calculate the black liquor solids content as the difference between the total solids in the sample and the tall oil yield computed to its equivalent sodium soap (based on the saponification number). The tall oil soap plus the water content is considered to account for all materials other than black liquor solids.

(*b*) Calculate the percentage of tall oil soap as follows:

$$\text{Tall oil soap, per cent} = Y\left(1 + \frac{(23 - 1)S}{56.1(1000)}\right)$$

$$= Y(1 + 0.000392S)$$

where:

Y = tall oil yield, per cent, and

S = saponification number.

(*c*) Calculate the black liquor solids, by difference, as follows:

$$\text{Black liquor solids, per cent} = T - O$$

where:

T = total solids, per cent, and

O = tall oil soap, per cent.

(*d*) Report the results to two significant figures.

REPORT OF COMMITTEE D-18

ON

SOILS FOR ENGINEERING PURPOSES*

Committee D-18 on Soils for Engineering Purposes held its annual meeting at Chicago, Ill., on June 16, 1954. Executive subcommittee meetings were held on June 14, 1954, at Chicago, Ill., and on January 11, 1955, at Washington, D. C.

A Symposium on Permeability of Soils (*STP No. 163*) was held during the Annual Meeting of the Society in June, 1954. A single session on general soils subjects was also held consisting of five papers. Two of the papers were on the subject of Lateral Load Tests on Piles and were published as *STP No. 154-A*, a supplement to the 1953 Symposium on Lateral Load Tests on Piles (*STP No. 154*). The remaining papers appear in the 1954 *Proceedings*.

The first C. A. Hogentogler Memorial Award of Committee D-18 was given to A. A. Wagner for his paper, "Lateral Load Tests on Piles for Design Information," which appears in *STP No. 154*. This award was established in 1953 for the outstanding paper presented in any period at a session sponsored by Committee D-18.

Following the main committee meeting on June 16, 1954, a special informal session was held for the purpose of discussing a paper prepared by D. M. Burmister on the subject of "Judgment Factors in Soil Testing." A symposium is being held on this subject during the 1955 Annual Meeting of the Society.

Organization Changes.—Section B of Subcommittee R-10 on Pile Load Bearing Tests was redesignated Subcommittee R-11 under A. E. Cummings, chairman. Subcommittee G-4 on Evaluation of Data was disbanded. Section D of Subcommittee R-3 was established to study and prepare a method for determining the relative density of cohesionless free-draining soils.

The present officers and Executive Committee members were re-elected for an additional 2-year term.

H. H. Miller, committee member, died during the past year.

Committee D-18 now consists of 124 individual members and 17 consultants. There are 96 voting memberships divided as follows: producers, 17; consumers, 40; and general interest members, 39.

REVISION OF TENTATIVE

The committee recommends the following revision of Tentative Specifications for Materials for Soil-Aggregate Subbase, Base, and Surface Courses (**D 1241 – 52 T**):[1]

Table I.—Change to read as shown in the accompanying Table I.

REAPPROVAL OF STANDARDS

The committee recommends that the following standards which have stood for 6 or more years without revision be reapproved without change:

*** Presented at the Fifty-eighth Annual Meeting of the Society, June 26–July 1, 1955.**

[1] 1952 Book of ASTM Standards, Part 3.

Standard Method of:

Preparing Soil Samples for Mechanical Analysis and Determination of Subgrade Soil Constants (**D 421 – 39**),

Test for Centrifuge Moisture Equivalent of Soils (**D 425 – 39**),

Test for Field Moisture Equivalent of Soils (**D 426 – 39**), and

Test for Shrinkage Factors of Soils (**D 427 – 39**),

(These standards will be reviewed by Subcommittee R-3 during the next year.)

Test for Moisture-Density Relations of Soil-Cement Mixtures (**D 558 – 44**),

Wetting and Drying Test of Compacted Soil-Cement Mixtures (**D 559 – 44**),

Freezing and Thawing Test of Compacted Soil-Cement Mixtures (**D 560 – 44**), and

Test for Cement Content of Soil-Cement Mixtures (**D 806 – 47**).

(Subcommittee R-8 and the joint D-4, D-18 Subcommittee state that these standards are being used most effectively and satisfactorily and no changes are contemplated.)

Tentative Method of:

Test for Moisture-Density Relations of Soils (**D 698 – 42 T**),

Revisions are being formulated by Subcommittee R-3. It is planned to report on these revisions at the next meeting.

Test for Shear Strength of Flexible Road Surfaces, Subgrades, and Fills by the Burgraf Shear Apparatus (**D 916 – 47 T**),

Testing Soil-Bituminous Mixtures (**D 915 – 47 T**),

Test to Determine the Bearing Capacity of Soil for Static Load on Spread Footings (**D 1194 – 52 T**),

Repetitive Static Load Tests of Soils for Use in Evaluation and Design of Airport and Highway Pavement (**D 1195 – 52 T**),

Non-Repetitive Static Load Tests of Soils for Use in Evaluation and Design of Airport and Highway Pavement (**D 1196 – 52 T**), and

Test for Load-Settlement Relationship for Individual Piles (**D 1143 – 50 T**).

Revisions of this tentative method are being considered by Subcommittee R-11 which recommended that it be continued in its present status for the present time.

TABLE I.—GRADATION REQUIREMENTS FOR SOIL-AGGREGATE MATERIALS.
(Table I, D 1241.)

Sieve Size (Square Openings)	Percentage by Weight Passing Square Mesh Sieves					
	Type I				Type II	
	Gradation A	Gradation B	Gradation C	Gradation D	Gradation E	Gradation F
2-in.	100	100	...	...	...	...
1-in.	...	75 to 95	100	100	100	100
3/8-in.	30 to 65	40 to 75	50 to 85	60 to 100	...	...
No. 4 (4760 micron)	25 to 55	30 to 60	35 to 65	50 to 85	55 to 100	70 to 100
No. 10 (2000 micron)	15 to 40	20 to 45	25 to 50	40 to 70	40 to 100	55 to 100
No. 40 (420 micron)	8 to 20	15 to 30	15 to 30	25 to 45	20 to 50	30 to 70
No. 200 (74 micron	2 to 8	5 to 20	5 to 15	10 to 25	6 to 20	8 to 25

TENTATIVES CONTINUED WITHOUT REVISION

The Committee recommends that the following tentatives, which have stood for 2 or more years, be continued without change:

Tentative Definitions of Terms and Symbols Relating to:

Soil Mechanics (**D 653 – 42 T**),

Revisions are being prepared by Subcommittee G-3 but are not ready for committee action.

The recommendations in this report have been submitted to letter ballot of the committee, the results of which will be reported at the Annual Meeting.[2]

SUBCOMMITTEE ACTIVITIES

Subcommittee G-1, Editorial (E. E. Bauer, chairman) reviewed proposed changes for tentative Method D 1143 – 50 T.

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[2] The letter ballot vote on these recommendations was favorable; the results of the vote are on record at ASTM Headquarters.

Subcommittee G-2 on Special Papers (R. Horonjeff, chairman) reviewed six papers for the Soils Session to be held at the 1955 Annual Meeting.

Subcommittee G-3 on Nomenclature and Definitions (C. R. Foster, chairman) has continued the review with the parallel ASCE committee of 600 terms proposed by the subcommittee. Eighty terms have been covered and agreed upon to date.

Subcommittee R-2 on Sampling and Related Field Testing for Soil Investigation (J. O. Osterberg, chairman) has continued work to develop the following standards: Method for Soil Investigations and Sampling by Auger Borings, Method for Penetration Test and Split Spoon Sampling of Soils, and Method of Thin-Walled Tube Sampling of Soils. The Canadian Standards Assn. and the Diamond Core Drill Manufacturers Assn. have asked to cooperate in the formulation of these proposed methods, and their suggestions and criticisms to tentative drafts are awaited. It is hoped that some action can be taken on these methods shortly.

Subcommittee R-3 on Physical Characteristics of Soils (E. E. Bauer, chairman) is considering requests for revisions to the Method of Mechanical Analysis of Soils (D 422 – 51), and some research testing is being undertaken in this direction relative to the hydrometer test. Work on a revision of the Test for Moisture-Density Relations of Soils (D 698 – 42 T) has continued.

Subcommittee R-4 on Physical Properties of Soils (E. S. Barber, chairman) sponsored the Symposium on Permeability Testing of Soils (*STP No. 163*). Work has begun on developing a method for testing the permeability of soils.

Subcommittee R-6 on Physico-Chemical Properties of Soils (J. H. Havens, chairman) has formulated plans for an informal seminar on the subject of physico-chemical properties of soils at the subcommittee meeting during the 1955 Annual Meeting.

Subcommittee R-9 on Dynamic Properties of Soils (R. K. Bernard, chairman) is continuing the preparation of a glossary of terms referring to soil dynamics.

Subcommittee R-11 on Pile Load Bearing Tests (A. E. Cummings, chairman) is reviewing proposed revisions of Tentative Method D 1143 – 50 T. Consideration is also being given to a method for lateral load tests on piles.

Special Subcommittee to Review the Special Publication entitled "Procedures for Soil Testing" (W. G. Holtz, chairman) is reviewing the test procedures appearing in this publication.

Symposium on Committee Work (R. F. Leggett, chairman) has arranged for the presentation of five papers at a symposium at the Annual Meeting which will provide a critical review of the past committee activities, the value of some standardization of soil tests for soil mechanics studies, and use of judgment in testing and evaluating test data.

Special Committee on C. A. Hogentogler Award reviewed eligible papers and will submit a recommendation for presentation of an award at the 1955 Annual Meeting.

This report has been submitted to letter ballot of the committee, which consists of 96 voting members; 64 members returned their ballots, of whom 63½ have voted affirmatively and 0 negatively.

Respectfully submitted on behalf of the committee,

E. J. KILCAWLEY,
Chairman.

W. G. HOLTZ,
Secretary.

REPORT OF COMMITTEE D-19

ON

INDUSTRIAL WATER*

Committee D-19 and its subcommittees met on June 16 to 18, 1954, in Chicago, Ill., and on February 2 to 4, 1955, in Cincinnati, Ohio. Its Advisory Subcommittee also met on October 19, 1954, in Pittsburgh, Pa.

The committee will sponsor a Symposium on High-Purity Water Corrosion,[1] consisting of the papers listed below, at the 1955 Annual Meeting of the Society:

"Methods of Preparing and Maintaining High-Purity Water," by F. N. Alquist, Dow Chemical Co.

"Effect of Material Composition in High-Temperature Water Corrosion," by A. H. Roebuck, Continental Oil Co.

"Special Study of Carbon and Low-Alloy Steels," by R. U. Blaser, The Babcock & Wilcox Co.

"The Influence of Water Composition on Corrosion in High-Temperature, High-Purity Water," by D. M. Wroughton, J. M. Seamon, and P. E. Brown, Westinghouse Electric Corp.

"The Use of Water in Atomic Reactors," by H. W. Huntley and S. Untermyer, General Electric Co.

The committee will also sponsor two Water Sessions at the Second Pacific Area National Meeting of the Society in September, 1956. The program for these sessions is being developed by L. Drew Betz.

The supply of the Manual on Industrial Water, ASTM Special Technical Publication *No. 148*, was exhausted in a little more than a year after its publication in February, 1953. A second printing of the Manual, *No. 148A*, was made in September, 1954. Although no change was made in the text, the second printing incorporates a detailed subject index and all tentatives and standards of the committee as of that date. Active work is in progress on extensive revisions and enlargements of the text for a second edition of the Manual.

The committee has completed a long considered and carefully studied reorganization, signalized by revised Regulations, to become effective July 1, 1955. Three significant changes are involved:

1. The privileges and nature of membership are more clearly defined so that each individual serving on the committee will have full membership status[1a] and the concurrent obligation to the work of the committee.

2. The subcommittees are converted to administrative groupings of related working Task Groups. The subcommittee chairman is responsible for coordinating the activities of the Task Groups under his supervision, reporting their progress and recommendations for approval by the whole committee. This change should improve both the economy and efficiency of the meeting time.

3. The authority of the Advisory Subcommittee, subject to the periodic approval of the whole committee, is increased in the area of assignment and distribution of effort within the committee. Appropriate reconstitution of the Advisory Subcommittee to correspond with these increased responsibilities has been accomplished by making its membership consist of the elected and appointed officers, plus six members-at-large elected from the committee.

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* Presented at the Fifty-eighth Annual Meeting of the Society, June 26–July 1, 1955.

[1] Issued as separate publication, *ASTM STP No. 179*.

[1a] Approved by the Board of Directors, May, 1955.

TABLE I.—VOLUME OF SAMPLE REQUIRED FOR DETERMINATION OF THE VARIOUS CONSTITUENTS OF INDUSTRIAL WATER.

	Volume of Sample,[a] ml
PHYSICAL TESTS	
*Color and Odor	100 to 500
*Corrosivity	flowing sample
*Electrical conductivity	100
*pH, electrometric	100
*Specific gravity	100
*Temperature	flowing sample
*Toxicity	1000 to 20 000
*Turbidity	100 to 1000
CHEMICAL TESTS	
Dissolved Gases:	
†Ammonia, NH_3	100
†Carbon Dioxide, free CO_2	100
†Chlorine, free Cl_2	100
†Hydrogen, H_2	1000
†Hydrogen sulfide, H_2S	500
†Oxygen, O_2	250 to 1000
†Sulfur Dioxide, free SO_2	100
Miscellaneous:	
Acidity and alkalinity	100
Bacteria, iron	100
Bacteria, sulfate-reducing	100
Biochemical oxygen demand	100 to 500
Carbon dioxide, total CO_2 (including CO_3^{--}, HCO_3^-, and free)	100 to 200
Chemical oxygen demand (dichromate)	50 to 100
Chlorine requirement	2000 to 4000
Chlorine, total residual Cl_2, (including OCl^-, $HOCl$, NH_2Cl, $NHCl_2$, and free)	100 to 200
Chloroform - extractable matter	1000
Detergents	100 to 200
Hardness	50 to 100
Hydrazine	50 to 100
Microorganisms	100 to 200
Volatile and filming amines	500 to 1000
Oily matter	3000 to 5000
Organic nitrogen	500 to 1000
Phenolic compounds	800 to 4000
Miscellaneous:	
pH, colorimetric	10 to 20
Polyphosphates	100 to 200
Silica	50 to 1000
Solids, dissolved	100 to 20 000
Solids, suspended	50 to 1000
Tannin and lignin	100 to 200
Cations:	
Aluminum, Al^{+++}	100 to 1000
†Ammonium, NH_4^+	25 to 500
Antimony, Sb^{+++} to Sb^{+++++}	100 to 1000
Arsenic, As^{+++} to As^{+++++}	100 to 1000
Barium, Ba^{++}	100 to 1000
Cadmium, Cd^{++}	100 to 1000
Calcium, Ca^{++}	100 to 1000
Chromium, Cr^{+++} to Cr^{++++++}	100 to 1000
Copper, Cu^{++}	100 to 4000
†Iron, Fe^{++} and Fe^{+++}	100 to 1000
Lead, Pb^{++}	100 to 4000
Magnesium, Mg^{++}	100 to 1000
Manganese, Mn^{++} to $Mn^{+++++++}$	100 to 1000
Mercury, Hg^+ and Hg^{++}	100 to 1000
Potassium, K^+	100 to 1000
Nickel, Ni^{++}	100 to 1000
Silver, Ag^+	100 to 1000
Sodium, Na^+	100 to 1000
Strontium, Sr^{++}	100 to 1000
Tin, Sn^{++} and Sn^{++++}	100 to 1000
Zinc, Zn^{++}	100 to 1000
Anions:	
Bicarbonate, HCO_3^-	100 to 200
Bromide, Br^-	25 to 100
Carbonate, CO_3^{--}	100 to 200
Chloride, Cl^-	25 to 100
Cyanide, Cn^-	25 to 100
Fluoride, Fl^-	25 to 100
Hydroxide, OH^-	50 to 100
Iodide, I^-	25 to 100
Nitrate, NO_3^-	10 to 100
Nitrite, NO_2^-	50 to 100
Phosphate, ortho, PO_4^{---}, HPO_4^{--}, $H_2PO_4^-$	50 to 100
Sulfate, SO_4^{--}, HSO_4^-	100 to 1000
Sulfide, S^{--}, HS^-	100 to 500
Sulfite, SO_3^{--}, HSO_3^-	50 to 100

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[a] Volumes specified in this table should be considered as a guide for the approximate quantity of sample necessary for the particular analysis. The exact quantity used should be consistent with the volume prescribed in the standard method of analysis, whenever the volume is specified.

* Aliquot may be used for other determinations.

† Samples for unstable constituents must be obtained in separate containers, preserved as prescribed, completely filled and sealed against all exposure.

The committee has established a new Subcommittee V on Testing Procedures and has changed the title of Subcommittee VI to "Corrosivity and Performance Testing."

At present, the declassified committee numbers 124 members.

RECOMMENDATIONS ACCEPTED BY THE ADMINISTRATIVE COMMITTEE ON STANDARDS

Subsequent to the 1954 Annual Meeting, Committee D-19 presented to the Society through the Administrative Committee on Standards the recommendation that the Method of Test for Evaluating Acute Toxicity of Industrial Waste to Fresh-Water Fishes (D 1345 – 54 T) be published as tentative.

This recommendation was accepted by the Standards Committee on September 28, 1954, and the tentative method appears in the 1954 Supplement to Book of ASTM Standards, Part 7.

PROPOSED METHOD FOR PUBLICATION AS INFORMATION

Committee D-19 on Industrial Water recommends the publication as information only of the Non-Referee Method of Test for Total Orthophosphate in Industrial Water as appended hereto.[2] This method is based on and represents a simplification of the ASTM Method D 515 – 43. The committee had been requested to prepare this simplified and abbreviated procedure by the chairman of the Chemical Section, Subcommittee on the Care of Pressure Vessels in Service, of the ASME Boiler Code Committee, and it is expected the method will be used in the Appendix of Section 7 on the Care of Power Boilers, of the ASME Boiler Test Code.

NEW TENTATIVE

The committee recommends the publication as tentative of the Method of Test for Hydrazine in Industrial Water as appended hereto.[3]

REVISION OF TENTATIVES

The committee recommends that the following 10 methods be revised as indicated and continued as tentative:

Tentative Methods of Sampling Industrial Water (D 510 – 54 T):[4]

Section 3.—Change to read as follows:

3. (*a*) The terms "industrial water," "biological tests," and "sterile" in these methods are defined in accordance with the Definitions of Terms Relating to Industrial Water and Industrial Waste Water (ASTM Designation: D 1129),[5] as follows:

Industrial Water.—Water (including its impurities) used directly or indirectly in industrial processes.

Biological Tests.—Examination for the purpose of determining the presence, identity, numbers, or effects of the presence of any organism in industrial water.[6]

Sterile.—Free from any viable organism, either active or dormant.[6]

(*b*) For definitions of other terms used in these methods, refer to Definitions D 1129.

Table I.—Substitute the accompanying Table I for the present Table I.

Tentative Methods of Test for Silica in Industrial Water (D 859 – 50 T):[5] Completely revised as appended hereto.[7]

Tentative Methods of Test for Acidity and Alkalinity in Industrial Water (D 1067 – 51 T):[5] Completely revised as appended hereto.[7]

Tentative Method of Test for Iron in Industrial Water (D 1068 – 49 T):[5] Completely revised as appended hereto.[7]

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[2] See p. 551.

[3] The new tentative appears in the 1955 Book of ASTM Standards, Part 7.

[4] 1954 Supplement to Book of ASTM Standards, Part 7.

[5] 1952 Book of ASTM Standards, Part 7.

[6] See p. 543.

[7] The revised tentative appears in the 1955 Book of ASTM Standards, Part 7.

Tentative Methods of Test for Hardness in Industrial Water (D 1126 – 53 T):[7]

Section 14.—Change the last sentence of Paragraph (*d*) to read: "Store the solution in a tightly stoppered, dark-colored bottle to reduce deterioration due to air and light (Note 3). This solution has a storage life of about one month."

Add the following note:

NOTE 3.—The indicator can be prepared, stored, and used in powder form rather than liquid form. The powder has a storage life of at least one year. It is prepared by grinding 0.2 g of Chrome Black T with 80 g of powdered NaCl. A dark-colored bottle should be used for storage. Suitable powdered hardness indicator is available from several commercial sources.

Renumber "Note 3" to read "Note 4."

Section 15(a).—Change the fourth sentence to read: "Add 2 or 3 drops of hardness indicator and stir (Note 5)."

Add the following note, renumbering the subsequent notes accordingly:

NOTE 5.—If powdered indicator is used, add a sufficient quantity of it to produce the required depth of color (approximately 0.2 g).

Footnote 10.—Change this footnote to read:

[10] For conversion factors, see the Method of Reporting Results of Analysis of Industrial Water (ASTM Designation: D 596).

Tentative Methods of Test for Fluoride Ion in Industrial Water (D 1179 – 51 T):[5] Revised as appended hereto.[7]

Tentative Specifications for Reagent Water (D 1193 – 52 T):[5] Revised, as appended hereto.[7]

Tentative Method of Test for Chemical Oxygen Demand (Dichromate Oxygen Demand) of Industrial Waste Water (D 1252 – 53 T):[8]

Section 8(e).—Change to read as follows:

(*e*) For waste water of low (5 to 50 ppm) chemical oxygen demand, a more dilute solution of $K_2Cr_2O_7$ may be used. A 0.025 *N* solution is recommended. However, if a 0.025 *N* solution is used, the sample size should be selected so that the dichromate reduction is not less than 25 per cent nor more than 50 per cent.

Tentative Methods of Test for Sulfides in Industrial Waste Water (D 1255 – 53 T):[8]

Section 9(a).—Add the following sentence at the end of this paragraph: "Where interferences are known to be absent, this step may be omitted."

Tentative Method of Test for pH of Industrial Waste Water (D 1293 – 53 T):[8]

Title.—Change to read: "Tentative Method of Test for pH of Industrial Water and Industrial Waste Water."

Section 1.—Change to read as follows:

1. This method covers the procedure for the electrometric measurement of pH of industrial water and industrial waste water by means of the glass electrode, and is intended for control and routine use.

REVISIONS OF STANDARDS AND REVERSION TO TENTATIVE

The committee recommends that the following three standards be revised as appended hereto, and reverted to tentative status:[9]

Standard Method of Test for Chloride Ion in Industrial Water (**D 512 – 49**),[5]

Standard Method of Test for Total Orthophosphate and Calculation of the Respective Orthophosphate Ions in Industrial Water (**D 515 – 43**),[5] and

Standard Method of Test for Sulfate Ion in Industrial Water (**D 516 – 49**).[5]

ADOPTION OF TENTATIVES AS STANDARD, WITHOUT REVISION

The committee recommends that the following two tentative methods be approved for reference to letter ballot of the Society for adoption as standard without change:

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[8] 1953 Supplement to Book of ASTM Standards, Part 7.

[9] The revised tentatives appear in the 1955 Book of ASTM Standards, Part 7.

Tentative Method of Reporting Results of Analysis of Industrial Water and Industrial Waste Water (**D 596 - 54 T**),[4] and

Tentative Method for Examination of Water-Formed Deposits by Chemical Microscopy (**D 1245 - 52 T**).[5]

ADOPTION OF TENTATIVE AS STANDARD WITH REVISIONS

The committee recommends that the Tentative Method of Test for Iodide and Bromide Ions in Industrial Water (**D 1246 - 52 T**)[5] be approved for reference to letter ballot of the Society for adoption as standard with the following change:

Section 8(c).—Change to read as follows:

(*c*) Reduce the excess bromine by adding sodium formate solution until the yellow tinge in the sample disappears; then add an excess of 1 ml of the sodium formate solution. Wash down the sides of the flask with a small amount of water and blow out bromine vapors by the use of a syringe and a glass tube inserted through the mouth of the flask. Add 0.5 g of $KF \cdot 2H_2O$ if any iron precipitates at this point.

REVISION OF STANDARD, IMMEDIATE ADOPTION

The committee recommends for immediate adoption the following revisions of the Standard Definitions of Terms Relating to Industrial Water (**D 1129 - 54**),[4] and accordingly asks for the necessary nine-tenths affirmative vote at the Annual Meeting in order that the revisions may be referred to the letter ballot of the Society:

Title.—Change to read: "Standard Definitions of Terms Relating to Industrial Water and Industrial Waste Water."

Eliminate the subdivision titles for Parts I, II, III, and IV. Discontinue such subdivision, and rearrange all definitions in alphabetical order.

Add the following new definitions:

Biological Tests.—Examination for the purpose of determining the presence, identity, numbers, or effects of the presence of any organism in industrial water. (D 510)

Sterile.—Free from any viable organism, either active or dormant. (D 510)

Acute Toxicity.—Any direct lethal action of pollution to fresh-water fishes that is demonstrable within 96 hr or less (Note). (D 1345)

NOTE.—The lethal action includes both internal and external effects, but excludes indirect action such as depletion of dissolved oxygen through chemical or biochemical oxidation of the test material.

Median Tolerance Limit (TL_m).—The concentration of pollutants at which 50 per cent of the test animals are able to survive for a specified period of exposure (Note). (D 1345)

NOTE.—The exposure period may be 24, 48, or 96 hr. The 24-hr TL_m and the 48-hr TL_m generally should be determined whenever the toxicity is sufficiently pronounced to permit their determination.

Critical Concentration Range.—The interval between the highest concentration at which all test animals survive for 48 hr and the lowest concentration at which all test animals die within 24 hr. (D 1345)

Change the following definitions to read:

Acidity.—The capacity of an aqueous solution containing a compound or compounds with or without dissociation or hydrolysis, or both, for neutralizing base to pH 7.0 or such other end points as mutually agreed upon by the parties concerned. (D 1067)

Alkalinity.—See Basicity.

Basicity (*Alkalinity*).—The capacity of an aqueous solution containing a compound or compounds with or without dissociation or hydrolysis, or both, for neutralizing acid to pH 7.0 or such other end points as mutually agreed upon by the parties concerned. (D 1067)

REAPPROVAL OF STANDARDS

The committee recommends that the following four standards which have stood without revision for six or more years be reapproved as standard without change in substance:

Standard Method of:

Test for Hydroxide Ion in Industrial Water (**D 514 - 47**),

Test for Manganese in Industrial Water (**D 858 – 49**),
Field Sampling of Water-Formed Deposits (**D 887 – 49**), and
Corrosivity Test of Industrial Water (NDHA Method) (**D 935 – 49**).

Methods D 514 and D 858 are being editorially revised to conform to the current Committee D-19 recommendations on form.

STANDARDS CONTINUED WITHOUT REVISION

The committee recommends that the following four standards be continued without revision:

Standard Method of:

Corrosivity Test of Industrial Water (USBM Embrittlement Detector Method) (**D 807 – 52**),
Test for Calcium Ion and Magnesium Ion in Industrial Water (**D 511 – 52**), with only editorial changes in form,
Identification of Crystalline Compounds in Water-Formed Deposits by X-ray Diffraction (**D 934 – 52**), with only editorial changes in form, and

Standard Specifications for:

Substitute Ocean Water (**D 1141 – 52**).

TENTATIVES CONTINUED WITHOUT REVISION

The committee recommends that the following ten tentatives be continued without revision pending completion of studies of possible changes:

Tentative Methods of Test for:

Dissolved Oxygen in Industrial Water (**D 888 – 49 T**),
Suspended and Dissolved Matter (Solids Suspended and Dissolved) in Industrial Water and Industrial Waste Water (**D 1069 – 54 T**),
Electrical Conductivity of Industrial Water (**D 1125 – 50 T**),
Sodium and Potassium in Industrial Water (**D 1127 – 50 T**),
Residual Chlorine in Industrial Water (**1253 – 53 T**),
Nitrite Ion in Industrial Water (**D 1254 – 53 T**),
Chlorine Requirements of Industrial Water and Industrial Waste Water (**D 1291 – 53 T**),
Odor of Industrial Waste Water (**D 1292 – 53 T**),
Identification of Types of Microorganisms in Industrial Water (**D 1128 – 50 T**), and
Tentative Scheme for Analysis of Industrial Water and Industrial Waste Water (**D 1256 – 53 T**).

The recommendations in this report have been submitted to letter ballot of the committee, the results of which will be reported at the Annual Meeting.[10]

ACTIVITIES OF SUBCOMMITTEES

Subcommittee I, Advisory (Max Hecht, chairman).—Considerable effort of the subcommittee was devoted to the matter of the reorganization of the committee. With the adoption of the revised Regulations, the Guide for the Administration and Operation of Committee D-19 on Industrial Water was completely revised.

The members-at-large elected via the letter ballot of this report to serve on the subcommittee include:

R. J. Austin	1956[11]
J. M. Seamon	1956
R. D. Hoak	1957
J. H. Phillips	1957
B. W. Dickerson	1958
R. F. Weston	1958

Changes made in the personnel of ASTM liaison representatives to other societies, and of liaison representatives from other societies to serve on Committee D-19, include:

R. F. Weston, Atlantic Refining Co., to the Committee on Standard Methods of Sewage and Industrial Waste Analysis of the Federation of Sewage and Industrial Waste Associations, succeeding L. D. Betz.

The resignation of R. F. Weston, the additional ASTM representative serving on the Subcommittee of Standards Methods for the Examination of Water and Sewage, of the American Public Health Assn.

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[10] The letter ballot vote on these recommendations was favorable; the results of the vote are on record at ASTM Headquarters.

[11] Term of office expires at end of Annual Meeting of year indicated.

The election to committee membership of the following:

A. R. Belyea, Consolidated Edison Co. of New York, Inc., as ASME representative.
W. C. King, New York, Chicago & St. Louis Railway, as the additional representative of the American Railways Engineering Assn.
F. U. Neat, Baltimore Gas and Electric Co., as the representative of the Edison Electric Inst.
W. G. Hamlin, as the representative of the Ohio River Valley Water Sanitation Commission (ORSANCO).
M. E. Holmberg, representing the National Association of Corrosion Engineers Committee 5C-1.

The committee regrets the loss by resignation of several active and productive members:

C. H. Fellows and J. B. Romer, both of whom were charter members of the committee,
R. T. Sheen, a former Secretary of Committee D-19,
W. E. Elliott, former Secretary of Subcommittee II, and
J. B. Smith, former chairman of Section C of Subcommittee VII.

The committee also records with sorrow the loss of C. C. Ruchoft, deceased, January, 1955. Dr. Ruchoft was a member of the staff of the United States Public Health Service, and was a widely recognized authority in his field. He contributed much to the work as a member of Subcommittee IV on Methods of Analysis of Industrial Water, and Subcommittee VII on Industrial Waste Water.

Subcommittee II, Definitions and General Specifications (S. K. Love, chairman): Section A, Manual (R. D. Hoak, chairman) has received from a majority of the authors outlines of chapters that will be rewritten and enlarged in the forthcoming second edition of the Manual. The second edition will include discussions of industrial waste water as well as industrial water. As soon as the integrated outline is approved, writing of the chapters will proceed.

Section B on Terminology and Nomenclature (R. E. Price, chairman) reports progress on proposed definitions for precision and accuracy. The section is restudying definitions now listed in Definition D 1129 with reference to editorial clarity.

Section D on General Specifications (R. J. Austin, chairman) has developed revisions of the specification for reagent water. Work was completed and approved for revision of Method D 596 on Reporting Results of Analysis.

Subcommittee III on Methods of Sampling (E. F. Davidson, chairman).—The subcommittee recommends:

The revision of the Tentative Methods of Sampling Industrial Water (D 510 - 54 T) to include (1) revisions of Table I—Volume of Sample Required for Determination of the Various Constituents of Industrial Water, (2) editorial changes to subject matter included under the heading of "Definitions" in the method. It was recommended that the method, with revisions incorporated, be retained as tentative and included in the annual report.

Continuation of the Standard Method of Field Sampling of Water-Formed Deposits (D 887 - 49), as a standard method without revision.

A new Task Group was formed with R. C. Ulmer as chairman to take over the future revisions of Tentative Methods of Sampling Steam (D 1066 - 54 T).

Subcommittee IV on Methods of Analysis (Frank E. Clarke, chairman), completed work on special ASME adaptations of ASTM methods for hardness, nitrite ion, hydroxide and sulfite ion and prepared a tentative adaptation on orthophosphate.

New tentatives were published on nonreferee sulfite testing, chloroform extractable matter, carbon dioxide, and suspended and dissolved matter (with Subcommittee VII).

Final drafts of new tentative methods have been prepared for phosphate, chloride, including mercurimetric titration, iron, sulfate, fluoride, and silica. Considerable progress has been made toward new tentative methods on acidity and basicity (with Subcommittee VII), organic matter, ammonia, dissolved oxygen, and scheme for analysis of deposits. Plans for an elaborate cooperative test clinic on dissolved oxygen test methods have been completed. Round-robin tests have been made on a tentative scheme for deposit analysis.

New task groups have been established on methods for hydrazine, zinc, lead, nickel, and volatile amines.

Subcommittee V on Testing Procedures (A. O. Walker, chairman), recently organized, is composed of the following task groups: Hydrogen, Optical Properties, Flame Photometer, Spectroscope, Spectrograph, Surface Tension, Oxidation and Reduction, Chemical Microscopy, Biological Microscope, X-ray Diffraction, Polarography, and Electrical Conductivity.

The subcommittee recommends:

The adoption as standard of the Tentative Method of Chemical Microscopy (D 1245 - 52 T), without revision.

The revision of the Tentative Method of Electrical Conductivity (D 1125 - 50 T), the revision to add material to clarify the sampling procedures. F. U. Neat and A. A. Berk were assigned to the Task Group to assist in this project.

The revision of the Tentative Method for Microorganisms (D 1128 - 50 T) to expand the method to cover more types of organisms than are presently covered.

It was recommended by the Task Group and approved by the subcommittee that the Method for Optical Properties be submitted for publication in the ASTM BULLETIN as information only.

The Task Groups on flame photometry, surface tension, and hydrogen have prepared drafts which were given general approval. Round-robin tests are being made on the flame photometer and surface tension methods. A new draft for the visual spectroscope is in preparation.

The Spectrograph Task Group will determine what liaison is desirable between the E-2 Subcommittee on Analyses of Non-Metallic Materials and Committee D-19.

Subcommittee VI on Corrosivity and Performance Testing (F. N. Alquist, chairman): The Task Group on Testing of Tubular Products for Corrosion and Deposits (R. S. Wise, chairman) has received considerable information on tests employing the apparatus first designed by the group. Although progress has been made, much work remains before a method can be written.

The Task Group on Radioactivity Testing (O. M. Elliott, chairman) has been unable to make significant progress in its current project to use radioactive tracers in the testing of hydraulic characteristics of gravity separators.

A Task Group on Ion Exchange Materials (A. R. Belyea, chairman) has been organized to prepare methods for evaluation of the performance of ion exchange materials. Progress has been made toward obtaining current test methods.

Subcommittee VII on Industrial Waste Water (L. Drew Betz, chairman): Section B, Methods of Analysis (R. F. Weston, chairman) has prepared new methods in cooperation with Subcommittee IV in addition to methods for oily matter in industrial waste water and for evaluating acute toxicity of industrial waste water to fresh water fishes. Revision of existing tentative methods for chemical oxygen demand and for sulfide ion has been recommended. New task groups were formed on chromium, specific gravity, residual chlorine, and detergents.

Section C, Gaging and Sampling of Industrial Waste Water, and Preservation of Samples (E. F. Mohler, Jr., chairman, replacing J. B. Smith, resigned) is planning to write a series of methods including modifications of ORSANCO and API procedures and methods of sampling with continuous sampling devices developed by Section C members. Full clearance has been granted by ORSANCO and by API to use data and methods from their respective manuals. Proper credit will be given to the sources whenever they are included.

Section D, Reporting Analyses of Industrial Waste Water (W. W. Hodge, chairman) discussed methods of reporting results of taste tests and tests of toxicity to aquatic life. Further studies are planned on reporting analytical results of such tests.

Subcommittee VII is revising its task groups to conform with the new organizational structure of Committee D-19. Sections are being abolished and future activities will be confined to task groups reporting through the subcommittee chairman, who appointed R. F. Weston as vice-chairman in charge of Analytical Procedures, E. F. Mohler, Jr., as vice-chairman in charge of Methods of Sampling, Gaging, and Preservation of Samples, and W. W. Hodge as vice-chairman in charge of Methods of Reporting Results. These appointments are effective July 1, 1955.

This report has been submitted to letter ballot of the committee, which consists of 124 members; 97 members returned their ballots, of whom 91 have voted affirmatively and 0 negatively.

Respectfully submitted on behalf of the committee,

MAX HECHT,
Chairman.

ORRIN M. ELLIOTT,
Secretary.

APPENDIX I

SUPPORTING DATA RELATING TO NEW AND REVISED METHODS OF TESTING INDUSTRIAL WATER AND INDUSTRIAL WASTE WATER

Supporting data relating to the new and revised methods for industrial water and industrial waste water, included in the Report of Committee D-19, are given in this Appendix.

Literature References Relating to the Proposed Revision of Standard Method of Test for Total Orthophosphate and Calculation of the Respective Orthophosphate Ions in Industrial Water (ASTM Designation: D 515 - 43)

Literature References:

(1) J. L. Kassner, H. P. Crammer, and M. A. Ozier, *Analytical Chemistry*, Vol. 20, p. 1052 (1948).
(2) J. L. Kassner and M. A. Ozier, *ibid.*, Vol. 22, p. 194 (1950).
(3) R. E. Kitson, with M. G. Mellon, *Industrial and Engineering Chemistry*, Analytical Edition, Vol. 16, p. 379 (1944).
(4) C. J. Barton, *Analytical Chemistry*, Vol. 20, p. 1068 (1948).
(5) L. Goldman and R. N. Love, Bureau of Mines, R. I., p. 3983 (1946).

Literature References and Supporting Data Relating to the Proposed Revision of Tentative Method of Test for Iron in Industrial Water (ASTM Designation: D 1068 - 49 T)

Literature References:

(1) L. G. Saywell and B. B. Cunningham, *Industrial and Engineering Chemistry*, Analytical Edition, Vol. 9, p. 67 (1937).
(2) F. C. Hummel and H. H. Willard, *ibid.*, Vol. 10, p. 13 (1938).
(3) W. B. Fortune, and M. G. Mellon, *ibid.*, Vol. 10, p. 60 (1938).
(4) M. L. Moss, M. G. Mellon, and G. F. Smith, *ibid.*, Vol. 14, p. 931 (1942).
(5) S. L. Bandemer and P. J. Schaible, *ibid.*, Vol. 16, p. 317 (1944).
(6) E. B. Sandell, "Colorimetric Determination of Traces of Metals," 2nd Edition, Interscience Publishers, Inc., New York, N. Y. (1950).
(7) M. G. Mellon, "Analytical Absorption Spectroscopy," John Wiley & Sons, Inc., New York, N. Y. (1950).
(8) W. W. Brandt, "Chelate Complexes of 1,10-Phenanthroline and Related Compounds," *Chemical Reviews*, Vol. 54, p. 959 (1954).

Supporting Data:

In a letter to W. A. Kirklin dated December 22, 1954, L. D. Betz reported the following data on the sensitivity of the method and possible effects due to the presence of calcium and magnesium:

Iron Present, ppm	Iron Found, ppm	Calcium as $CaCO_3$ Present, ppm	Magnesium as $CaCO_3$ Present, ppm
0.20..........	0.18	0.0	0.0
0.80..........	0.78	0.0	0.0
0.20..........	0.188	23.0	10.0

Supporting Data Relating to the Proposed Revision of Tentative Methods of Test for Fluoride Ion in Industrial Water (ASTM Designation: D 1179 - 51 T)

Supporting Data:

Several modifications of the zirconium - alizarin procedure for the determination of fluoride in water are published in the literature. The procedure

TABLE I.—EFFECT OF ALUMINUM

Aluminum Added, mg per 100 ml	Fluoride Added, mg per 100 ml	Fluoride Found, mg per 100 ml	Ratio of True to Apparent Fluoride
0.02	0.050	0.045	1.08
0.02	0.070	0.065	
0.02	0.100	0.095	
0.05	0.020	0.017	1.14
0.05	0.050	0.044	
0.05	0.070	0.061	
0.05	0.100	0.090	
0.10	0.050	0.040	1.24
0.10	0.070	0.055	
0.10	0.100	0.083	
0.16	0.050	0.037	1.35
0.16	0.100	0.075	
0.20	0.050	0.035	1.41
0.20	0.070	0.050	
0.20	0.100	0.072	
0.25	0.020	0.013	1.48
0.25	0.050	0.035	
0.30	0.050	0.032	1.56
0.30	0.070	0.044	
0.30	0.100	0.066	
0.40	0.050	0.030	1.67
0.40	0.070	0.042	
0.40	0.100	0.060	
0.50	0.050	0.027	1.83
0.50	0.070	0.038	
0.50	0.100	0.056	
0.60	0.050	0.025	2.00
0.60	0.070	0.035	
0.60	0.100	0.050	
0.80	0.050	0.020	2.32
0.80	0.100	0.045	
1.00	0.050	0.017	2.75
1.00	0.100	0.038	

TABLE II.—EFFECT OF HEXAVALENT CHROMIUM.

Chromium Added, mg per 100 ml	Fluoride Added, mg per 100 ml	Fluoride Error, mg per 100 ml	
		1 hr	7 to 18 hr
0.010	0.000	+0.005	+0.005
0.010	0.020	+0.004	+0.004
0.010	0.050	+0.002	+0.003
0.010	0.100	+0.001	+0.002
0.020	0.000	+0.005	+0.009
0.020	0.020	+0.003	+0.007
0.020	0.050	+0.003	+0.006
0.020	0.100	+0.002	+0.005
0.030	0.000	+0.005	+0.012
0.030	0.020	+0.003	+0.010
0.030	0.050	+0.003	+0.006
0.030	0.100	+0.002	+0.004
0.050	0.000	+0.005	+0.022
0.050	0.020	+0.003	+0.016
0.050	0.050	+0.003	+0.012
0.050	0.100	+0.002	+0.007
0.060	0.000	+0.007	...
0.060	0.020	+0.007	...
0.060	0.050	+0.003	...
0.060	0.100	+0.002	...
0.080	0.000	+0.012	...
0.080	0.020	+0.012	...
0.080	0.050	+0.007	...
0.080	0.100	+0.006	...
0.100	0.000	+0.015	...
0.100	0.020	+0.015	...
0.100	0.050	+0.010	...
0.100	0.100	+0.008	...

using the sulfuric acid indicator was originally developed by W. L. Lamar of the U. S. Geological Survey and was published in *Industrial and Engineering Chemistry*, Analytical Edition, in 1945. Since that time, the U. S. Geological Survey has studied this procedure extensively, and used it in the determination of fluoride in many thousands of water samples. A paper on the Study of Factors Affecting the Determination of Fluoride in Water with Zirconium - Alizarin, by W. L. Lamar and P. G. Drake, of the U. S. Geological Survey, has been submitted for publication in the *Journal of the American Water Works Association*. This procedure, as developed by the U. S. Geological Survey, also is published in part in the tenth edition of "Standard Methods for the Examination of Water, Sewage, and Industrial Wastes," published by the American Public Health Assn.

The procedure as submitted repre-

TABLE III.—EFFECT OF IRON, MANGANESE, SULFATE, CHLORIDE, NITRATE, AND ALKALINITY.

Concentration of Interfering Ions, mg per 100 ml		Fluoride Error, mg per 100 ml
Fe^{++}	0.2	0.000
	1.0	−0.001
	1.5	−0.002
	2.5	[a]
Fe^{+++}	0.2	0.000
	1.0	−0.001
	1.5	−0.002
	2.5	[a]
Mn^{++}	0.2	0.000
	1.0	−0.001
	1.5	−0.001
	2.5	0.000
SO_4^{--}	10	+0.002
	20	+0.002
	30	+0.003
	40	+0.006
	50	+0.009
	60	+0.011
	100	+0.018
	140	+0.029
	180	+0.037
	200	+0.038
Cl^-	20	−0.002
	30	−0.003
	40	−0.004
	50	−0.006
	60	−0.007
	100	−0.012
	200	−0.018
	300	−0.023
	400	−0.025
	500	−0.030
NO_3^-	10	−0.002
	20	−0.002
	30	−0.002
	40	−0.004
	50	−0.005
	60	−0.005
	80	−0.006
	100	−0.008
Alkalinity as $CaCO_3$	2.5	−0.002
	5.0	−0.002
	7.5	−0.003
	10.0	−0.005
	12.5	−0.006
	15.0	−0.007
	17.5	−0.009
	20.0	−0.011
	25.0	−0.013
	30.0	−0.017
	40.0	−0.023
	50.0	−0.028

[a] Obscured by color from the iron.

TABLE IV.—EFFECT OF HYDROGEN ION.

pH of Sample	Fluoride Error, mg per 100 ml
7.0	0.000
6.0	0.000
5.0	0.000
4.5	0.000
4.0	+0.002
3.5	+0.002
3.0	+0.004
2.8	+0.006
2.5	+0.010
2.2	+0.012

sents an extensive study of this method, and at the ASTM Meeting in Cincinnati, Ohio, the task group recommended that this procedure be presented to Committee D-19 for letter ballot.

The individual experimental data obtained is so extensive that its presentation here would involve an undue amount of space with little additional value. The pertinent data are summarized and presented in Tables I to IV, inclusive.

APPENDIX II

ABBREVIATED METHOD OF TEST FOR ORTHOPHOSPHATE IN WATER SUPPLIES IN THE EVAPORATIVE INDUSTRY

Committee D-19 recommends to the Society the publication as information only of the abbreviated method of test for orthophosphate described in this appendix. When the method has been accepted and published by the ASTM, Committee D-19 will recommend to the American Society for Mechanical Engineers that the method be used in the Appendix of Section 7 on the Care of Power Boilers, of the ASME Boiler Test Code.

PROPOSED NON-REFEREE METHOD OF TEST FOR TOTAL ORTHOPHOSPHATE IN INDUSTRIAL WATER[1]

Application

1. This method covers the colorimetric determination of orthophosphate in industrial water, except water that is highly polluted. It is intended primarily as a control procedure when high precision is not required.

Interference

2. High concentrations of ferric ions and chromate ions interfere with the test; however such concentrations generally are not present in the water for which this method is intended. Color and turbidity, which would interfere if present, are removed prior to color development.

Apparatus

3. Use one of the following means for color evaluation:

(*a*) *Matched Nessler Tubes*, 50-ml capacity.

(*b*) *Commercial Color Comparator*, with permanent standards.

(*c*) *Photometer.*—Spectrophotometer or filter photometer suitable for measurements at 620 mμ.

Reagents

4. (*a*) *Ammonium Molybdate Solution.*—Add 280 ml of sulfuric acid (H_2SO_4, sp gr 1.84) to about 700 ml of water. To this acid solution add slowly, and with constant stirring, 25 g of ammonium heptamolybdate ($(NH_4)_6Mo_7O_{24} \cdot 4H_2O$). Warm the mixture slightly, if necessary, to complete solution; then dilute to 1 liter with water.

(*b*) *Decolorizing Carbon.*—Analytical grade that will not add significant phosphate to the sample.[2]

(*c*) *Standard Phosphate Solution* (*1 ml = 0.1 mg PO_4*).—Dissolve 0.1433 g of oven-dried potassium phosphate, monobasic (KH_2PO_4) in water and dilute to 1 liter.

(*d*) *Stannous Chloride Solution.*—Dissolve 2.38 g of stannous chloride

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[1] This method is based on, and is a simplification of, Non-Referee Method C of the Tentative Methods of Test for Phosphate in Industrial Water (ASTM Designation: D 515). For details not presented herein, refer to Method D 515, 1954 Supplement to Book of ASTM Standards, Part 7.

[2] Nordite A, manufactured by American Nordite Co., Inc., Jacksonville, Fla., has been found satisfactory for this purpose.

($SnCl_2 \cdot 2H_2O$) in 25 ml of hydrochloric acid (HCl, sp gr 1.19) and store the solution in a dark glass or painted dropping bottle.

Calibration

5. (*a*) Prepare a series of phosphate standards covering PO_4^{---} concentrations from 0 to 5 ppm, in 1-ppm increments, by diluting 1 ml of the standard phosphate solution prepared in accordance with Section 4(*c*) to 100 ml with water, 2 ml of the standard phosphate solution to 100 ml with water, etc. Each additional milliliter of standard phosphate solution so diluted results in a solution having 1 ppm additional phosphate ion.

(*b*) Develop the colors of the series of standards as described for the sample in Section 6 (*b*).

(*c*) Determine the absorbance at 620 mμ for each standard with the photometer. Prepare a calibration curve plotting PO_4^{---} concentration against absorbance.

Procedure

6. (*a*) If the sample is turbid or colored, add two 0.25-g increments of decolorizing carbon to 200 ml of sample in an Erlenmeyer flask, shaking it vigorously for 1 min after each addition. Filter through a dry, medium-texture filter paper.[3]

(*b*) If the PO_4^{---} concentration is anticipated to be 5 ppm or less, pour 100 ml of clear, colorless sample into a 250-ml Erlenmeyer flask. If the concentration is anticipated to be more than 10 ppm, dilute a correspondingly smaller volume to 100 ml with water and pour the diluted sample into the Erlenmeyer flask. Add 4 ml of ammonium molybdate solution and mix by shaking the flask. Add 1 ml of $SnCl_2$ solution and shake the flask again.

(*c*) If visual comparison is to be made, transfer 50 ml of the sample solution to a Nessler tube and compare the color of the solution with the color of 50 ml of the standards prepared in accordance with Section 5 (*a*) and (*b*), and which are contained in a series of similar Nessler tubes. Record the PO_4^{---} concentration of the standard that most nearly matches the sample solution in color.

(*d*) If a commercial color comparator is to be used, treat the clear, colorless sample as directed in the instructions supplied by the comparator manufacturer, using the reagents provided with the comparator. Make color comparisons between the sample solution and the permanent standards with which the comparator is equipped. Record the PO_4^{---} concentration as directed by the comparator manufacturer.

(*e*) If photometric measurement is to be made, transfer part of the sample solution to the same size sample cell as was used in preparing the calibration curve in Section 5 (*c*). Determine the absorbance at 620 mμ with the photometer as directed in the instructions supplied with the photometer being used. Record the PO_4^{---} concentration indicated by the calibration curve as being equivalent to the absorbance determined.

Calculation

7. Calculate the concentration of orthophosphate, PO_4^{---}, in parts per million, as follows:

$$PO_4^{---}, \text{ppm} = \frac{C \times 100}{S}$$

where:

C = parts per million phosphate ion indicated by the matching standard or by the calibration curve, and

S = milliliters of sample tested directly or diluted before testing.

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[3] Whatman No. 40 filter paper has been found satisfactory for this purpose.

Precision and Accuracy

8. (*a*) *Precision.*—Duplicate results should not differ by more than the following:

Concentration Range, ppm	By Nessler Tubes or Commercial Comparator, Difference, ppm	By Photometer, Difference, ppm
0 to 10	4	2
10 to 25	4	2
25 to 100	10	4
100 to 200	20	10

(*b*) *Accuracy.*—Average results should not differ from the true concentration by more than the following:

Concentration Range, ppm	By Nessler Tubes or Commercial Comparator, Difference, ppm	By Photometer, Difference, ppm
0 to 10	±2	±1
10 to 25	±2	±1
25 to 100	±5	±2
100 to 200	±10	±5

REPORT OF COMMITTEE D-20
ON
PLASTICS*

Committee D-20 on Plastics, and its subcommittees, held three meetings during the year: at Chicago, Ill., on June 16 to 18, 1954; at Cleveland, Ohio, on November 15 to 17, 1954; and at Washington, D. C., on February 28 to March 2, 1955. The Advisory Committee also met at these times.

Committee D-20 continues to participate in the work of Technical Committee 61 of the International Organization for Standardization (ISO), the American Group for which has been set up under Committee D-20 with representation from other interested groups. A number of representatives from this country attended the last meeting of ISO/TC 61 held in Brighton, England, on October 4 to 8, 1954. Five test methods were approved as Draft ISO Recommendations. These relate to the determination of water absorption, apparent densities of molding powders pourable and nonpourable from a funnel, acetone soluble matter in phenolic moldings, and temperature of deflection under load. In addition, eight items were approved for circulation as Draft ISO Proposals. These pertain to a glossary of equivalent terms in English and French, determination of flexural properties of rigid plastics, standard conditioning of plastics prior to testing, standard laboratory atmospheres for testing plastics, determination of free phenols and of ammonia in phenol-formaldehyde moldings, determination of percentage of methanol soluble matter in polystyrene, and boiling water absorption characteristics of plastics.

The next meeting of ISO/TC 61 is scheduled for the first week of July, 1955, in Paris, France.

Committee D-20 has organized six new subcommittees in order to handle more effectively the development of specifications and particular test methods for engineering plastics products. One of these, Subcommittee XVII on Plastic Pipe and Fittings, is a joint committee with the Society of the Plastics Industry (SPI). The former Subcommittee I on Strength Properties and Subcommittee II on Hardness Properties have been consolidated as Subcommittee I on Mechanical Properties. Subcommittee IV on Optical Properties has been placed on temporarily inactive status.

The following subcommittee chairmen were newly appointed: G. W. Ingle, to Subcommittee IV on Optical Properties (inactive); B. G. Achhammer, to Subcommittee V on Permanence Properties; A. G. H. Dietz, to Subcommittee VIII on Research; P. E. Willard, to Subcommittee X on Definitions, Nomenclature, and Significance of Tests; A. C. Webber, to Subcommittee XV on Thermoplastic Materials; G. D. Johnston, to Subcommittee XVI on Thermosetting Materials; J. W. Sinner, to Subcommittee XVII (Joint SPI) on Plastic Pipe and Fittings; R. B. Crepps, to Subcommittee XVIII on Reinforced Plastics; Bill Williams, to Subcommittee XIX on Plastic Film and Sheeting 1; and C. H. Alexander, to Subcommittee XX on Cellular Plastics.

RECOMMENDATIONS ACCEPTED BY THE ADMINISTRATIVE COMMITTEE ON STANDARDS

Subsequent to the 1954 Annual Meeting, Committee D-20 presented to the

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* **Presented at the Fifty-eighth Annual Meeting of the Society, June 26–July 1, 1955.**

Society through the Administrative Committee on Standards a recommendation for the revision of Tentative Method of Test for Tensile Properties of Thin Plastic Sheets and Films (D 882 – 54 T).

This recommendation was accepted by the Standards Committee on September 28, 1954, and the revised method appears in the 1954 Supplement to the Book of ASTM Standards, Part 6.

RECOMMENDATIONS AFFECTING STANDARDS

The committee is recommending the revision of 10 tentatives, the revision and reversion to tentative of one standard, the adoption as standards of 6 tentatives, the revision of one standard for immediate adoption, and the reapproval of 5 standards. The standards affected, together with the revisions recommended, are given in detail in the Appendix.[1]

The committee has considered all of the other tentatives, not mentioned in the Appendix, which are under its jurisdiction and which have been published for two years or longer, and recommends that they be continued in their present status until further revisions in them are made as contemplated.

The recommendations in this report have been submitted to letter ballot of the committee, the results of which will be reported at the Annual Meeting.[2]

ACTIVITIES OF SUBCOMMITTEES

Subcommittee I on Mechanical Properties (R. M. Berg, chairman).—The scope of this subcommittee has been expanded to include that of the discharged Subcommittee II on Hardness Properties, and it is carrying on the work of standardizing procedures for two indentation hardness methods, the new Rockwell J scale for soft or semirigid plastics, and the Shore D Durometer. Revisions, concerning speeds of testing for some plastics, are in progress for the Tentative Methods of Test for Tensile Properties of Plastics (D 638 – 52 T) and for Flexural Properties of Plastics (D 790 – 49 T). Variations in the type of notches and apparatus variations are being studied toward possible revision of the Tentative Method of Test for Impact Strength of Plastics and Electrical Insulating Materials (D 256 – 54 T), and development of other kinds of impact tests for sheet materials is being considered. Work is in progress on a number of methods applicable to plastic films. Methods for measurement of stiffness have been studied by round-robin tests, and early revision for improvement of the Standard Method for Estimating Blocking of Plastic Sheets (D 884 – 48) is expected. The Tentative Method of Test for Tear Resistance of Plastic Film and Sheeting (D 1004 – 49 T) is being revised in line with the recent revisions in the Tentative Method of Test for Tensile Properties of Thin Plastic Sheets and Films (D 882 – 54 T), and an adaptation applicable to plastic films of the Standard Method of Test for Internal Tearing Resistance of Paper (D 689 – 44) is being considered. A round-robin study of a number of methods for dynamic testing has been presented, and the advisability of development of a test method for measuring dynamic properties, based on one or more of the techniques, is under consideration.

Subcommittee III on Thermal Properties (C. H. Adams, chairman) is conducting a second round-robin test program for development of a method of test for flammability of thin films incorporating changes in procedure indicated by results of an earlier round robin. Review of the three present Standard Methods of Test for Flammability of Plastics, Self-Extinguishing Type (D 757 – 49), Over 0.050 in. in Thickness (D 639 – 44), and 0.050 in. and Under (D 568 – 43), is planned for the near future to determine the reproducibility and to clarify the significance of the tests. A method for determining viscosity by parallel plate plastometry is being prepared. Editorial revisions have been prepared to clarify the significance of the Tentative Method of Test for Flow Rates of Thermoplastics by Extrusion Plastometer (D 1238 – 52 T) in application to polyethylene plastics. Further revision of this method in line with a recent British Standards Institution revision of its method for "melt index" of polyethylene, to be proposed to ISO/TC 61, is being considered. Consideration is also being given to development of additional methods for characterizing flow properties of thermoplastics which will relate to processability. Editorial changes have been made in the Tentative Method for Heat Distortion Temperature of Plastics (D 648 – 45 T) to minimize misinterpretation of results, and further changes to clarify the significance are being considered. A method for determining stress relaxation behavior for load bearing applications is being studied. Revision of the Tentative Method of Test for Brittleness Temperature of Plastics and Elastomers by Impact (D 746 – 54 T) has been completed, and a method for brittleness temperature of thin films is to be developed.

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[1] See p. 559.

[2] The letter ballot vote on these recommendations was favorable; the results of the vote are on record at ASTM Headquarters.

Subcommittee V on Permanence Properties (B. G. Achhammer, chairman).—The development of uniform recommended practices for operation of carbon-arc exposure apparatus has been referred to Committee E-1 on Methods of Testing. Study of available light sources for the replacement of the S-1 sun lamp in the Standard Method of Test for Colorfastness of Plastics to Light (D 620 – 49) and the Standard Recommended Practice for Accelerated Weathering of Plastics (D 795 – 49) is continuing. Fluorescent sun lamps are being considered for use in an accelerated aging test. The addition of distilled water to the list of reagents in Tentative Method of Test for Resistance of Plastics to Chemical Reagents (D 543 – 52 T) and the addition of a long-term equilibrium immersion test to the Standard Method of Test for Water Absorption of Plastics (D 570 – 42) are being considered. A round-robin test program on gas permeability of films was initiated, and a tentative procedure for outdoor exposure of plastics is in preparation.

Subcommittee VII on Analytical Methods (H. E. Riley, chairman).—Development of a method for determining heat stability of plasticizers has been referred to Committee D-23 on Cellulose and Cellulose Derivatives. Work on a method for determining specific gravity of polyethylene has been initiated. A round-robin test program on proposed methods for estimating available ammonia, formaldehyde, and phenols in molded phenolic plastics has been initiated. Proposed methods for estimating particle size of vinyl resins are being considered. Methods for measuring effectiveness of heat stabilizers and for electrical conductivity in vinyl resins are contemplated.

Subcommittee VIII on Research (A. G. H. Dietz, chairman).—The subcommittee arranged for presentation of four papers of considerable current interest to the committee at its spring, 1955, meeting, as follows:

"Development of a Vibrating Reed Method for Measurement of Dynamic Properties," by Stephen Strella of the U. S. Department of the Army,

"Stress Cracking (Crazing) of Polystyrene," by E. E. Ziegler of the Dow Chemical Co., "The Flow Behavior of Molten Polyethylene," by A. M. Birks of Canadian Industries Ltd. (1954), and

"Characterization of Polyethylene," by W. G. Oakes of Imperial Chemical Industries Ltd., Alkali Division.

Subcommittee IX on Molds and Molding Processes (J. L. Williams, chairman). Work is in progress toward revision of the Tentative Recommended Practice for Injection Molding of Specimens of Thermoplastic Molding Powder (D 1130 - 50 T). Development of a new transfer mold and molding procedure is being initiated, and a mold design and molding procedure for compression molding of sheet for test specimen preparation are being prepared. The subcommittee is cooperating with Committee E-11 on Quality Control in revising the sampling procedure in the Standard Methods of Testing Molding Powders Used in Manufacturing Molded Electrical Insulators (D 392 - 38). The effect on properties of the gating point in the standard test bar mold is to be studied.

Subcommittee X on Definitions, Nomenclature, and Significance of Tests (P. E. Willard, chairman).—Definitions of a number of terms for addition to the Tentative Definitions of Terms Relating to Plastics (D 883 - 54 T) have been developed. Development of definitions of additional terms is in progress. Revisions have been made in the Tentative Nomenclature of Descriptive Terms Pertaining to Plastics (D 675 - 54 T), and further revisions in line with present usage are contemplated.

Subcommittee XIV on Conditioning (G. H. Mains, chairman).—A revision of the Standard Methods of Conditioning Plastics and Electrical Insulating Materials for Testing (D 618 - 53) to include three additional temperatures corresponding to the limits of new AIEE and IEC insulation classes is being balloted in the subcommittee, as well as a revision of the Tentative Specifications for Enclosures and Servicing Units for Tests Above and Below Room Temperature (D 1197 - 54 T) to clarify testing requirements. Efforts are being made to arrange a symposium in the near future on experience in conditioning large laboratory spaces to ASTM standard testing conditions. The work of this subcommittee is a joint activity with Committee D-9 on Electrical Insulating Materials.

Subcommittee XV on Thermoplastic Materials (A. C. Webber, chairman).—In this new subcommittee have been organized twelve sections corresponding to those of the former Subcommittee VI on Specifications concerned with thermoplastics. A new tentative specification for nonrigid vinyl chloride and copolymer compounds is nearly completed and preparation of a specification for rigid compounds has been initiated. Tentative Specifications for Polystyrene (D 703 - 49 T), and for Methacrylate (D 788 - 48 T), Molding Compounds are being revised. Proposed specifications for styrene-rubber plastics, for styrene-acrylonitrile copolymer plastics, for chlorotrifluoroethylene plastics, and for tetrafluoroethylene plastics are nearly completed after extensive round-robin testing to establish properties values and specific test methods. Extensive revision of the Tentative Specifications for Nylon Molding and Extrusion Compositions (D 789 - 53 T) is being undertaken to include additional commercial compositions, to emphasize tests for identification of compositions as well as quality, and also to include appropriate engineering information and recommended end uses. An editorial addition has been incorporated in the Tentative Specifications for Polyethylene Molding and Extrusion Materials (D 1248 - 52 T) in order to explain its present status and point out possibly misleading information pending its revision. Work is in progress toward revision of these specifications to include additional grades suitable for specific applications, such as in pipe and cable, and to develop necessary characterizing test methods for such grades. Study of possible tests to characterize plasticizers for use in electrical applications is to be undertaken.

Subcommittee XVI on Thermosetting Materials (G. D. Johnston, chairman).—Four sections have been organized in this new subcommittee, corresponding to those of the former Subcommittee VI on Specifications which were concerned with thermosetting materials excluding laminates. Revisions of specifications for phenolic, urea-formaldehyde, and melamine-formaldehyde molding compounds have been prepared as presented in this report. Revision of Tentative Specifications for Polyester Molding Compounds (D 1201 - 52 T) to include glass-filled types is in progress, and specifications for allyl molding compounds are in preparation.

Subcommittee XVII on Plastic Pipe and Fittings (J. W. Sinner, chairman).—Eight sections have been organized in this new subcommittee, five of them on specifications for pipe, and three on test methods. Development of necessary test methods and dimensional standards for specifications is in progress in cooperation with other organizations interested in pipe. The work of this subcommittee is a joint activity with the Society of the Plastics Industry.

Subcommittee XVIII on Reinforced Plastics (R. B. Crepps, chairman).—Five sections have been organized in this new subcommittee covering specifications and methods of test for flat sheet, rods and tubes, corrugated sheet, laminating resins, and reinforcements. Specifications for epoxy-glass laminates and for several kinds of reinforcements are being prepared. Surveys are being made of test methods for laminated rods and tubes, for polyester resins, and for corrugated panels. A light transmission test and a loading test developed by the SPI for corrugated panels are under consideration.

Subcommittee XIX on Plastic Film and Sheeting (Bill Williams, chairman).—In this new subcommittee, five sections covering the major types of thermoplastic film and sheeting have been organized. Study of proposed industry specifications for vinyl sheeting is under way. A survey of needs in test methods specific for polyethylene sheeting is being undertaken. Canvass of interest in development of specifications for styrene sheeting is being made. A revision of the Standard Specifications for Cast Methacrylate Sheets, Rods, Tubes, and Shapes (D 702 - 46) is nearly completed.

This report has been submitted to letter ballot of the committee, which consists of 194 members; 121 members returned their ballots, of whom 104 have voted affirmatively and 0 negatively.

Respectfully submitted on behalf of the committee,

R. K. WITT,
Chairman.

G. M. ARMSTRONG,
Secretary.

APPENDIX

RECOMMENDATIONS AFFECTING STANDARDS ON PLASTICS

In this appendix are given proposed revisions in certain standards and tentatives which are referred to earlier in this report. These standards and tentatives appear in their present form in the 1952 Book of ASTM Standards, Part 6, or in its 1953 or 1954 Supplements, as indicated by the final number in the ASTM designation.

Revision of Tentatives

Committee D-20 recommends that the following 10 tentatives be revised as indicated and continued as tentative:

Tentative Specifications for Phenolic Molding Compounds (D 700 - 54 T):

(Jointly with Committee D-9 on Electrical Insulating Materials.)

Section 2.—Add the following new types:

Type 14.—General purpose wood-flour filled rubber-modified phenolplastic.

Type 15.—General purpose rubber-modified phenolplastic with a cellulose filler which may be wood-flour or cotton flock.

Type 16.—Moderate impact strength rubber-modified phenolplastic with chopped cotton fabrics or other suitable forms of cellulose filler to give the required strength for this type.

Type 17.—Medium impact strength rubber-modified phenolplastic with chopped cotton fabrics or other suitable forms of cellulose filler to give the required strength for this type.

Type 18.—Heat-resistant mineral-filled rubber-modified phenolplastic.

Section 3(b).—Add the following to the table in this section:

Type	Particle Size[a] U. S. Standard Sieve No.[b]	Pourability,[a] max, sec	Apparent Density,[a] min, g per cu cm	Bulk Factor,[a] max
14	10	30	0.40	3.5
15	10	...	0.40	3.5
16	...	...	0.30	4.0
17	...	...	0.15	8.0
18	10	25	0.60	2.5

Table I.—Add the requirements as shown in the accompanying Table I.

Tentative Specifications for Laminated Thermosetting Materials (D 709 - 52 T):

(Jointly with Committee D-9 on Electrical Insulating Materials.)

This specification is revised in order to bring it in line with present NEMA Standards and Military Specifications, and to clarify certain items.

Table V.—After 1.0 in third line add superscript "*c*" with the following explanatory note under the table: "[c] In the case of Grade G-7 the maximum permissible warp or twist shall be 1.5 per cent."

Table VII.—Change the flexural strength values for Grades ES-1, ES-2, ES-3, to 13500 psi for LW and CW in all thicknesses in order to reach agreement with MIL-P-78A.

Table VIII.—Change impact values for Grades ES-1, ES-2, ES-3, to 0.25 LW and 0.22 CW in order to have agreement with MIL-P-78A. Also change impact value of Grade P to 0.50 LW and 0.45 CW.

TABLE I.—DETAIL REQUIREMENTS FOR MOLDED TEST SPECIMENS.
(Addition to Table I, D 700.)

	Type 14	Type 15	Type 16	Type 17	Type 18
Water absorption, max, weight gain, per cent	1.5	1.5	1.5	1.5	0.3
Specific gravity, 23/23 C (73.4/73.4 F) max	1.35	1.35	1.35	1.35	1.70
Flexural strength, min, psi	7 000	7 000	7 000	7 000	6 000
Impact strength, (Izod), min, ft-lb per in. of notch	0.35	0.45	0.80	2.00	0.30
Tensile strength ($\frac{1}{8}$ in. specimen), min, psi	3 500	4 000	4 000	4 000	4 000
Compressive strength, min, psi	15 000	15 000	15 000	15 000	15 000
Modulus in flexure, max, psi	4×10^5	4×10^5	5×10^5	5×10^5	8×10^5
Mold shrinkage in. per in.:					
Min	0.005	0.004	0.004	0.002	0.004
Max	0.010	0.009	0.008	0.006	0.008
Insulation resistance min, megohms	100	100	100	100	100
Dielectric strength, min v per mil:					
Short-time test	275	300	275	250	275
Step-by-step test	225	275	225	200	225

Section 8(a).—Replace this section, including Note 11, with the following:

8. (*a*) *Length and Width.*—The tolerances in length and width of manufacturers standard size sheets shall be plus or minus one inch from the manufacturers standard.

NOTE 11.—Due to variations in sizes of press equipment, there is considerable variation in the lengths and widths of manufacturers standard size sheets. For most of the grades, these standard sizes range between 36 in. and 50 in. in width, and between 36 in. and 90 in. in length. Certain grades are sometimes supplied in standard sizes ranging from 24 in. to 36 in. in width, and from 24 in. to 96 in. in length. For tolerances in length and width of cut pieces see Table XXI.

Table XXII.—Revise by adding the value 0.005 in. in fourth column opposite 0.025 in. thickness, under Grades ES-1, ES-2, ES-3, CE, and A.

Revise note b to include Grade CE after Grade PC, to read "for grades PC and CE it is $\frac{1}{32}$ in.:"

Table XXV.—Revise as shown below in Tables II and III in order to include a separate table for round tubes (Table XXV) and a separate table for square and rectangular tubes (Table XXVI) to prevent confusion because of the differ-

TABLE II.—PERMISSIBLE VARIATIONS IN CUT LENGTHS OF ROUND TUBES.
(Table XXV, D 709.)

Length, in.	Permissible Variations, Plus or Minus, in. Outside Diameter				
	$\frac{3}{16}$ to 2 in., incl	Over 2 to 4 in. incl	Over 4 in.	Over 4 to 8 in.,	Over 8 in.
3 and under	0.010	0.010	0.030	...	...
Over 3 to 6, incl	0.010	0.015	0.030	...	...
Over 6 to 12, incl	0.015	0.020	0.030	...	...
Over 12 to 48, incl	$\frac{1}{32}$	$\frac{1}{32}$	$\frac{3}{64}$	...	...
Over 48 to 72, incl	$\frac{1}{16}$	$\frac{5}{64}$	...	$\frac{3}{32}$	$\frac{3}{16}$
Over 72 to 96, incl	$\frac{3}{32}$	$\frac{3}{32}$	...	$\frac{1}{8}$	$\frac{1}{4}$

TABLE III.—PERMISSIBLE VARIATIONS IN CUT LENGTHS OF SQUARE AND RECTANGULAR MOLDED TUBES.
(New Table XXVI, D 709.)

Length, in.	Permissible Variations, Plus or Minus, in. Outside Diameter		
	$\frac{3}{16}$ to 2 in., incl	Over 2 to 4 in., incl	Over 4 in.
3 and under	0.010	0.010	0.030
Over 3 to 6, incl	0.010	0.015	0.030
Over 6 to 12, incl	0.015	0.020	0.030
Over 12 to 48, incl	$\frac{1}{32}$	$\frac{1}{32}$	$\frac{3}{64}$

ences in size ranges available in the two general shapes. Renumber all succeeding tables accordingly.

Table XXXIII, Permissible Variations in Cut Lengths of Molded Rods.—Revise in order that requirement 0.030 in. be changed to $\frac{1}{32}$ in. in both columns.

Table XLI (Appendix III).—Add the superscript "*h*" in two places following "Maximum operating temperature, continuous, deg Fahr" and the following explanation below the table: "[h] Experience indicates that laminates will give satisfactory service in most applications at these temperatures. Property values at these temperatures will not approach those obtained at room temperature. The detailed effect of elevated temperatures on property values is under investigation."

Table XLI.—Add superscript "*k*" in two places following "AIEE insulation class" and the following explanation below the table: "[k] AIEE Definitions of Insulation Classes are shown in Appendix III preceding Table XLI."

Appendix III Preceding Table XLI.—Add the following:

The laminated thermosetting products covered by these specifications, most of which are used extensively for electrical insulating materials, may be classified by AIEE Standards in accordance with the following descriptions:

Class of Insulation	Description of Material
A	Class A insulation consists of (1) cotton, silk, paper, and similar organic materials when either impregnated[a] or immersed in a liquid dielectric; (2) molded and laminated materials with cellulose filler, phenolic resins, and other similar resins of similar properties; (3) films and sheets of cellulose acetate and other cellulose derivatives of similar properties; and (3) varnishes (enamel) as applied to conductors. The limiting insulation temperature (hottest spot temperature) for this class is 105 C (221 F).
B	Class B insulation consists of mica, asbestos, fiberglass, and similar inorganic materials in built-up form with organic binding substances. A small portion of Class A materials may be used for structural purposes only.[b] The limiting insulation temperature (hottest spot temperature) for this class is 130 C (266 F).
H	Class H insulation consists of (1) mica, asbestos fiberglass, and similar inorganic materials in built-up form with binding substances composed of silicone compounds, or materials with equivalent properties; and (2) silicone compounds in rubbery or resinous forms, or materials with equivalent properties. A minute proportion of Class A materials may be used only where essential for structural purposes during manufacture.[c] The limiting insulation temperature (hottest spot temperature) for this class is 180 C (356 F).

Tentative Specifications for Melamine-Formaldehyde Molding Compounds (D 704 – 51 T):

The revision of these specifications consists of bringing strength values into line with experience on present types and to include as an additional type a glass fiber reinforced material.

Section 2.—Reword first sentence and add Type 8 as follows:

These specifications cover the following eight types of melamine-formaldehyde molding compounds:

Type 8.—A glass fiber reinforced material with high impact strength, good electrical properties, and flame resistance.

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[a] An insulation is considered to be "impregnated" when a suitable substance replaces the air between its fibers, even if this substance does not completely fill the spaces between the insulated conductors. The impregnating substances, in order to be considered suitable, must have good insulating properties; must entirely cover the fibers and render them adherent to each other and to the conductor; must not produce interstices within itself as a consequence of evaporation of the solvent or through any other cause; must not flow during the operation of the machine at full working load or at the temperature limit specified; and must not undully deteriorate under prolonged action of heat.

[b] The electrical and mechanical properties of the insulated winding must not be impaired by application of the temperature permitted for Class B material. (The word "impaired" is here used in the sense of causing any change which could disqualify the insulating material for continuous service.) The temperature endurance of different Class B insulation assemblies varies over a considerable range, in accordance with the percentage of Class A materials employed, and the degree of dependence placed on the organic binder for maintaining the structural integrity of the insulation.

[c] The electrical and mechanical properties of the insulated winding must not be impaired by the application of the temperature permitted for Class H material. (The word "impaired" is here used in the sense of causing any change which could disqualify the insulating material for continuous service.)

Section 4.—Change to read as follows:

4. Test specimens molded in accordance with the Recommended Practice for Molding Specimens of Amino Plastics (ASTM Designation: D 956) shall conform to the requirements as to physical and electrical properties prescribed in Table I.

Table I.—Change flexural strength and deflection values for all types and add values for Type 8 as shown in the accompanying Table IV.

Section 6.—Change Paragraphs (*a*), (*g*), (*h*), (*i*), and (*j*) as indicated below:

(*a*) *Conditioning Test Specimens.*—Molded test specimens of melamine-formaldehyde plastics shall be conditioned in accordance with Procedure B of the Tentative Methods of Contioning Plastics and Electrical Insulating Materials for Testing (ASTM Designation: D 618), except for the tests for arc resistance and dielectric strength, where Procedure A shall be used.

(*g*) *Shrinkage.*—Standard Method of Measuring Shrinkage from Mold Dimensions of Molded Materials Used for Electrical Insulation (ASTM Designation: D 551).

(*h*) *Dielectric Strength.*—Reletter and delete reference to conditioning.

(*i*) *Loss Factor.*—Tentative Methods of Testing Molded Materials Used for Electrical Insulation (ASTM Designation: D 48) and Tentative Methods of Test for Power Factor and Dielectric Constant of Electrical Insulating Materials (ASTM Designation: D 150).

(*j*) *Arc Resistance.*—Reletter.

Tentative Specifications for Cellulose Acetate Molding Compounds (D 706 - 51 T):

The revision corrects certain values now shown in error, and permits an alternate method of conditioning.

Table II, "Detail Requirements for Molded Test Specimens.—The values shall be revised as follows:

Formula Reference No. Designation	2 MH-1	8 MH-2	13 MH-3	3 MS-1	9 MS-2	5 H_6-1	6 H_4-1	11 H_4-2	1 H_2-1	7 H_2-2	12 H_2-3	4 S_2-1	10 S_2-2
Deformation Under Load at 50 C (Cold flow), per cent 1000-psi load	2.0	3.0	3.0	9.0	17.0	1.0	1.0	1.0	2.0	2.0	2.0	...	...
(Values now shown in error	...	...	...	...	...	...	...	...	...	...	...	35	35)
2000-psi load	...	...	...	...	...	...	...	...	...	...	...	...	...
(Values now show in error	...	...	...	...	30	...	...	...	...	...	...	...	...)

In Paragraph 6(*c*), the alternate method of conditioning (24 hr at 50 C (122 F)) shall be substituted for the preferred method of conditioning (48 hr over anhydrous calcium chloride at 73 F).

Tentative Specifications for Cellulose Acetate Butyrate Molding Compounds (D 707 - 51 T):

These specifications are being revised to correct certain values now shown in error, and to permit an alternate method of conditioning.

Table II, Detail Requirements for Molded Test Specimens.—The values shall be revised as follows:

Formula Reference No. Designation	7 MH-1	2 MH-2	10 MH-3	8 MS-1	3 MS-2	11 MS-3	5 H_4-1	6 H_2-1	1 H_2-2	9 H_2-3	4 S_2-1	12 S_2-2
Deformation Under Load at 50 C (Cold flow), per cent 1000-psi load	2	3	5	8	13	20	1	2	2	3	...	...
(Values now shown in error	...	...	...	...	...	...	...	...	...	...	35	35)
2000-psi load	16	...	19	...	...	...	...	...	...	5	...	...
(Values now shown in error	7	...	7	30	...	30	...	...	...	4	...	...)

TABLE IV.— DETAIL REQUIREMENTS FOR COMPRESSION MOLDED TEST SPECIMENS.
(Table I, D 704.)

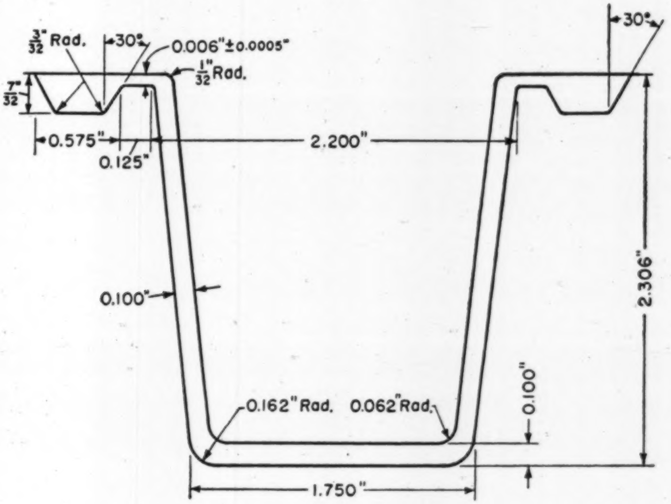
	Type 1	Type 2	Type 3	Type 4	Type 5	Type 6	Type 7	Type 8
Specific Gravity, 23/23 C (73.4/73.4 F):								
Min								1.94
Max								2.00
Flexural Strength, min, psi	10 000	7 400	12 000	11 000	9 500	6 500	5 800	10 000
Flexural Deflection,[a] min, inches	0.085	0.040	0.092	0.095	0.110	0.063	0.055	0.060
Impact Strength (Izod), min, ft-lb per in. of notch								4.00
Water Absorption (24-hr, immersion), max weight gain, per cent								0.21
Mold Shrinkage, max, in. per in.								0.003
Dielectric Strength, min v/mil:								
Short-time test								170
Step-by-step test								170
Loss Factor, max:								
60 cps								2.5
1000 cps								0.45
1,000,000 cps								0.19
Arc Resistance, min, sec								180

In Paragraph 6(*c*), the alternate method of conditioning (24 hr at 50 C (122 F)) shall be substituted for the preferred method of conditioning (48 hr over anhydrous calcium chloride at 73 F).

Tentative Method of Test for Measuring the Molding Index of Thermosetting Molding Compounds (D 731 - 54 T):

This revision is recommended to clarify the design of the mold and to control more closely the flow of the materials.

Figure 1.—Change as shown in the accompanying Fig. 1.



Note:-
All Surfaces Highly Polished
Rockwell C-58 Steel. Tolerances
on Dimensions are ± 0.001 in.,
Except as Noted

FIG. 1.—Cup Mold.

Tentative Method of Test for Brittleness Temperature of Plastics and Elastomers by Impact (D 746 – 54 T):

Revise as appended hereto,[1] in order to provide an operating procedure which will result in agreement between the two available types of testing apparatus.

Tentative Methods of Sampling and Testing Plasticizers Used in Plastics (D 1045 – 49 T):

This method is being revised to provide a method for measurement of refractive index, by addition of paragraphs as follows:

REFRACTIVE INDEX[a]

17. *Apparatus.* (*a*) *Refractometer.*—An Abbe refractometer with scale graduated directly in terms of refractive index of the D line of sodium at a temperature of 23 C.

(*b*) *Water Supply.*—A water supply, the temperature of which may be varied.

18. *Procedure.* (*a*) The refractometer shall be placed in front of a suitable source of light (either daylight or electric light), the thermometer inserted and circulation of water adjusted so as to bring the prisms to the desired temperature (usually 23 C (73.4 F)). Clean with alcohol and wipe dry. A drop of the liquid to be tested shall then be spread upon the lower prism after which the prisms shall be clamped. The mirror shall then be adjusted so that the light enters the telescope. The eyepiece shall be focussed on the cross hairs and the reading lens of the scale. Upon moving the prism arm, a position can now be found where the lower part of the field is dark and the upper part light. In general, the borderline will be colored and this is corrected by turning the milled head on the right of the telescope so that a sharp black and white edge is obtained. The prism arm is now moved until this black edge just crosses the intersection of the cross-hairs. The refractive index shall then be read off on the scale, the fourth decimal place being estimated.

(*b*) The accuracy of the instrument may be checked by a small test plate of known refractive index, which is supplied with the refractometer. This test plate shall be attached to the upper prism with a liquid of high refractive index (usually mono-bromnaphthalene). Errors may be corrected by means of a small adjusting screw.

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[a] Taken from D 901 – 52 T, Methods of Testing Askarels.

Tentative Nomenclature of Descriptive Terms Pertaining to Plastics (D 675 – 54 T):

Revise to clarify the descriptions of certain terms and to bring them into agreement with present usage, as follows:

Bloom.—A visible exudation or efflorescence on the surface of a plastic. NOTE: Bloom can be caused by lubricant, plasticizer, etc.

Frosting.—A light-scattering surface resembling fine crystals. (See also *Chalking, Haze, Bloom.*)

Haze.—Indefinite, cloudy appearance within, or on the surface of, a plastic not describable by the terms *Chalking, Frosting,* or *Bloom.* (For measurement of *Haze* see method D 1003.)

Open Bubble.—Use *Pit.* Delete term from "Recommended Nomenclature" and place under "Terms Not Recommended."

Pimple.—Undesirable, small, sharp or conical elevation on the surface of a plastic, whose form resembles a pimple in the common meaning. (See also *Blister.*)

Tentative Definitions of Terms Relating to Plastics (D 883 – 54 T):

Add the following new definitions:

Bulk Factor.—The ratio of the volume of a molding compound or powdered plastic to the volume of the solid piece. Also, the ratio of the density of the solid plastic object to the apparent density of the loose molding powder.

Cure, v.—To change the properties of a plastic or resin by chemical reaction, which for example may be condensation, polymerization, or addition; usually accomplished by the action of either heat or catalyst, or both, and with or without pressure.

Deterioration, n.—A permanent change in the physical properties of a plastic evidenced by impairment of these properties.

Gel, n.—A semisolid system exhibiting a yield point and consisting of a network of polymeric solid containing liquid.

Inhibitor, n.—A substance which prevents or retards a chemical reaction.

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[1] The revised tentative appears in the 1955 Book of ASTM Standards, Part 1.

Insert, n.—An object molded or cast into a plastic part for a definite purpose.

Molding, Blow.—A method of forming objects from plastic masses by inflating with compressed gas.

Molding, Contact Pressure.—A method of molding or laminating in which the pressure is only slightly more than necessary to hold the materials together during the molding operation. This pressure is usually less than 10 psi.

Molding, High-Pressure.—Molding or laminating in which the pressure used is greater than 200 psi.

Molding, Injection.—A method of forming plastic objects from granular or powdered plastics by fusing the plastic in a chamber with heat and pressure and then forcing part of the mass into a cooler chamber where it solidifies.

NOTE.—This method is commonly used to form objects from thermoplastics.

Molding, Low-Pressure.—Molding or laminating in which the pressure used is 200 psi or less.

Molding, Transfer.—A method of forming plastic objects from granular, or preformed, powdered plastics by fusing the plastic in a chamber with heat and then forcing essentially the whole mass into a hot chamber where it solidifies.

NOTE.—This method is commonly used to form objects from thermosetting plastics.

Permanence.—The property of a plastic which describes its resistance to appreciable changes in characteristics with time and environment.

Plastics Welding.—The joining of two or more pieces of plastic by fusion of the material in the pieces at adjoining or nearby areas either with or without the addition of plastic from another source.

Polystyrene, n.—A plastic based on a resin made by polymerization of styrene as the sole monomer. (See Styrene Plastics.)

NOTE.—Polystyrene may contain minor proportions of lubricants, stabilizers, fillers, pigments, and dyes.

Prepolymer, n.—A chemical structure intermediate between that of the monomer or monomers and the final polymer or resin.

Rubber, n.—A natural or synthetic material that can be or is already vulcanized to a state in which it has high extensibility and forcible quick retraction. (See also *Elastomer* and *Plastic.*)

Softening Range.—The range of temperature in which a plastic changes from a rigid to a soft state.

NOTE.—Actual values will depend on the method of test. Sometimes referred to as softening point.

Styrene-Rubber Plastics.—Plastics consisting of at least 50 per cent styrene plastics combined with rubbers and other compounding ingredients.

REVISION OF STANDARD AND REVERSION TO TENTATIVE

Committee D-20, jointly with Committee D-23 on Cellulose and Cellulose Derivatives, recommends that the Standard Method of Test for Acetyl and Butyryl Content of Cellulose Acetate Butyrate (**D 817 – 49**) be extensively revised, as appended hereto, to extend its scope and provide procedures for complete testing of cellulose acetate butyrate similar to those provided for cellulose acetate in Standard Methods of Testing Cellulose Acetate (D 871 – 48), and reverted to tentative status.[1]

ADOPTION OF TENTATIVES AS STANDARD

The committee recommends that the following six tentatives be approved for reference to letter ballot of the Society for adoption as standard without revision:

Tentative Specifications for:

Ethyl Cellulose Molding Compounds (**D 787 – 52 T**),

Tentative Methods of Test for:

Volatile Loss from Plastic Materials (**D1203 – 52 T**),
Resistance of Plastic Films to Extraction by Chemicals (**D 1239 – 52 T**),
Shrinkage of Molded and Laminated Thermosetting Plastics at Elevated Temperature (**D 1299 – 53 T**), and
Total Chlorine in Vinyl Chloride Polymers and Copolymers (**D 1303 – 53 T**),

Tentative Recommended Code for:

Designating Form of Material and Direction of Testing Plastics (**D 1009 – 49 T**).

REVISION OF STANDARD, IMMEDIATE ADOPTION

The committee recommends for immediate adoption the following revision of the Standard Specifications for Urea-Formaldehyde Molding Compounds (**D 705 - 49**) in order to bring strength values in line with experience and to clarify the intent of the conditioning requirements, and accordingly requests the necessary nine-tenths affirmative vote at the Annual Meeting in order that this revision may be referred to letter ballot of the Society.

Section 4.—Change to read as follows:

> Test specimens molded in accordance with the Recommended Practice for Molding Specimens of Amino Plastics (ASTM Designation: D 956) shall conform to the requirements as to physical properties prescribed in Table I.

Table I.—Change the values for flexural strength to read as follows:

	Grade 1	Grade 2
Flexural Strength, min, psi	8000	7500

Section 6.—Change Paragraphs (*a*) and (*g*) to read as follows:

> (*a*) *Conditioning Test Specimens.*—Molded test specimens of urea-formaldehyde plastics shall be conditioned in accordance with Procedure B of the Tentative Methods of Conditioning Plastics and Electrical Insulating Materials for Testing (ASTM Designation: D 618), except for the tests for arc resistance and dielectric strength, where Procedure A shall be used.
>
> (*g*) *Dielectric Strength.*—Delete reference to conditioning.

REAPPROVAL OF STANDARDS

The committee recommends the reapproval of the following five standards which have been published for six or more years without revision:

Standard Methods of Test for:

Mar Resistance of Plastics (**D 673 - 44**),
Shear Strength of Plastics (**D 732 - 46**),
Impact Resistance of Plastics at Subnormal and Supernormal Temperatures (**D 758 - 48**),
Tensile and Compressive Properties of Plastics at Subnormal and Supernormal Temperatures (**D 759 - 48**), and

Standard Recommended Practices for:

Determining Permanent Effect of Heat on Plastics (**D 794 - 49**).

REPORT OF COMMITTEE D-21

ON

WAX POLISHES AND RELATED MATERIALS*

Committee D-21 on Wax Polishes and Related Materials held two meetings during the year: at New York City on December 9 and 10, 1954, and at Chicago, Ill., on May 18, 1955.

Additions and changes during the year brought the total membership of the committee to 67, of whom 32 are classified as producers, 14 as consumers, and 21 as general interest members. There is one consulting member.

REVISION OF TENTATIVES

The committee recommends the following revision of the Tentative Method of Test for Nonvolatile Matter (Total Solids) in Water Emulsion Waxes (**D 1289 - 53 T**):[1]

Section 4(a).—Change the oven temperature from "105 to 110 C" to read "105 ± 2.5 C," and the heating time from "6 hr" to read "4 hr."

TENTATIVES CONTINUED WITHOUT REVISION

The committee recommends that the following tentative methods be continued as tentative without revision:

Tentative Method of Test for:

Total Ash and Silica in Water Emulsion Waxes (**D 1288 - 53 T**), and

Sediment in Water Emulsion Wax by Means of Centrifuge (**D 1290 - 53 T**).

The recommendations in this report have been submitted to letter ballot of the committee, the results of which will be reported at the Annual Meeting.[2]

ACTIVITIES OF SUBCOMMITTEES

Subcommittee I on Nomenclature (J. T. Hohnstine, chairman) is continuing its work on definitions of terms requested by the other subcommittees. A review of all approved definitions is now under way by correspondence.

Subcommittee II on Raw Materials (Melvin Fuld, chairman) is making progress on the development of test methods for the acid and saponification values of natural waxes. In addition, a task force is currently reviewing methods of determining the melting point of waxes.

Subcommittee III on Physical and Chemical Testing (Gerald De Napoli, chairman) has completed the revision of the Tentative Method of Test for Nonvolatile Matter (Total Solids) in Water Emulsion Waxes (D 1289 - 53 T) referred to in this report. The development of methods for the determination of total solids and flash point of solvent waxes is also continuing. Methods for determining the viscosity and stability of water emulsion floor waxes are also being examined.

Subcommittee IV on Performance

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* Presented at the Fifty-eighth Annual Meeting of the Society, June 26–July 1, 1955.

[1] 1953 Supplement to Book of ASTM Standards, Part 4.

[2] The letter ballot vote on these recommendations was favorable; the results of the vote are on record at ASTM Headquarters.

Tests (C. S. Kimball, chairman).—The section on slip resistance is continuing its work on the development of a ground glass surface for use as a secondary standard for the calibration of the Sigler and James type slip testers. The section on service life is investigating methods of testing water spot resistance of water emulsion waxes. They are also studying methods for the evaluation of dirt retention properties of floor waxes. The section on appearance has completed its investigation of four methods of application of water emulsion waxes and plans to recommend them in the near future for publication as information only. The group is now working on methods for the test application of automobile polishes.

Subcommittee V on Specifications (William Joy, chairman) is drawing up a specification for water emulsion floor wax. Where test methods are available, numerical limits are being included. Completion of this specification awaits development of test methods for many of the properties involved.

This report has been submitted to letter ballot of the committee, which consists of 67 members; 39 members returned their ballots, of whom 35 have voted affirmatively and 0 negatively.

Respectfully submitted on behalf of the committee,

W. W. WALTON,
Chairman.

B. S. JOHNSON,
Secretary.

EDITORIAL NOTE

Subsequent to the Annual Meeting, Committee D-21 presented to the Society through the Administrative Committee on Standards the following recommendations:

Tentative Method of Test for:

Acid Number (Empirical) of Natural Waxes (D 1386 – 55 T), and
Saponification Number (Empirical) of Natural Waxes (D 1387 – 55 T).

These recommendations were accepted by the Standards Committee on July 25, 1955, and the new methods of test appear in the 1955 Book of ASTM Standards, Part 4.

REPORT OF COMMITTEE D-22

ON

METHODS OF ATMOSPHERIC SAMPLING AND ANALYSIS*

Committee D-22 on Methods of Atmospheric Sampling and Analysis and its subcommittees held two meetings during the year: at New York City on September 14, 1954, and at Cincinnati, Ohio, on January 31 and February 1, 1955. The present membership of the main committee consists of 53 members, and four consulting members.

Officers elected at the September 1954 meeting to serve for a term expiring in 1956 were: Chairman, L. C. McCabe; Vice-Chairman, F. S. Mallette; Secretary, H. H. Schrenk.

RECOMMENDATIONS ACCEPTED BY THE ADMINISTRATIVE COMMITTEE ON STANDARDS

Subsequent to the 1954 Annual Meeting, Committee D-22 presented to the Society through the Administrative Committee on Standards the following recommendations:

Tentative Recommended Practice for:

Planning the Sampling of the Atmosphere (D 1357 - 55 T),

Tentative Definitions of:

Terms Relating to Atmospheric Sampling and Analysis (D 1356 - 55 T),

Tentative Methods for:

Determination of Concentration of Odorous Vapors (D 1354 - 55 T), and

Continuous Analysis and Automatic Recording of the Sulfur Dioxide Content of the Atmosphere (D 1355 - 55 T).

Method D 1355 and Definitions D 1356 were accepted by the Standards Committee on March 7, 1955; the remaining two items were accepted on March 23, 1955. These tentatives will appear in the 1955 Book of ASTM Standards, Part 7.

ACTIVITIES OF SUBCOMMITTEES

Subcommittee activities were reported in the April, 1955, BULLETIN, page 25. Current activity includes development of methods for stack sampling and for sampling gases, vapors, and particulate matter. Additional definitions are being developed to add to those previously approved. Methods for determining fluorine in vegetation and biological materials and for determining nitrogen dioxide and ozone in the atmosphere are being developed.

This report has been submitted to letter ballot of the committee, which consists of 53 members; 37 members returned their ballots, all of whom have voted affirmatively.

Respectfully submitted on behalf of the committee,

L. C. McCABE,
Chairman.

H. H. SCHRENK,
Secretary.

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* Presented at the Fifty-eighth Annual Meeting of the Society, June 26–July 1, 1955.

REPORT OF COMMITTEE D-23

ON

CELLULOSE AND CELLULOSE DERIVATIVES*

Committee D-23 on Cellulose and Cellulose Derivatives held one meeting during the year: in New York City, on September 13, 1954. The Executive Subcommittee met in New York City on February 24, 1955.

The committee is presently composed of 48 members, of whom 14 are classified as producers, 12 as consumers, and 22 as general interest members.

At the September meeting, the following officers were elected for a two-year term:

Chairman, F. A. Simmonds.
Vice-Chairman, L. B. Genung.
Secretary, W. W. Becker.
Members of Executive Committee, A. S. O'Brien, C. M. Conrad.

Subcommittee I on Nomenclature and Definitions has been without a chairman since D. E. Northrup resigned. Kyle Ward was appointed as new chairman of this subcommittee.

RECOMMENDATIONS ACCEPTED BY THE ADMINISTRATIVE COMMITTEE ON STANDARDS

Subsequent to the 1954 Annual Meeting, Committee D-23 presented to the Society through the Administrative Committee on Standards the following recommendations:

Tentative Methods of:

Testing Methylcellulose (D 1347 - 54 T), and
Test for Moisture in Cellulose (D 1348 - 54 T).

Revision and Reversion to Tentative of:

Standard Specifications and Tests for Soluble Nitrocellulose (D 301 - 50).

These recommendations were accepted by the Standards Committee on November 10, 1954, and the new and revised methods and specifications appear in the 1954 Supplement to Book of ASTM Standards, Part 4.

PROPOSED METHODS TO BE PUBLISHED AS INFORMATION

The committee recommends that the following methods be accepted for publication as information as appended hereto:[1]

Proposed Method of Test for:

Viscosity of Sodium Carboxymethylcellulose,
Degree of Etherification of Sodium Carboxymethylcellulose,

REVISION OF STANDARD AND REVERSION TO TENTATIVE

The committee recommends that the Standard Method of Test for Acetyl and Butyrl Content of Cellulose Acetate Butyrate (**D 817 - 49**)[2] be revised as appended hereto and reverted to tentative status.[3]

This method is under the joint jurisdiction of Committee D-23 and Committee D-20 on Plastics.

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* Presented at the Fifty-eighth Annual Meeting of the Society, June 26–July 1, 1955

[1] See pp. 573 and 575.

[2] 1952 Book of ASTM Standards, Part 6.

[3] The revised tentative appears in the 1955 Book of ASTM Standards, Part 4.

ACTIVITIES OF SUBCOMMITTEES

Subcommittee II on Cellulose (O. A. Battista, chairman) sponsored two panel discussions during the September, 1954, general D-23 meeting. The subjects covered and their respective discussion leaders were:

"Chromatographic Techniques for Determination of Hydrolysis Products of Cellulose," by Wayne E. Moore, Forest Products Laboratory, Madison, Wis.

"Present Status of Disperse Viscosity Method and Proposed Future Studies," by B. L. Browning, Institute of Paper Chemistry, Appleton, Wis.

The procedure for the determination of pentosans evolved through the efforts of the joint ACS-ASTM-TAPPI task group is being made available as an ASTM suggested procedure for general information.

The scope of the alpha-beta-gamma cellulose task group (to be redesignated the task group on cold alkali solubility tests for cellulose) has been extended to include nondilution alkali solubility tests for cellulose in addition to the classical alpha-beta-gamma procedures. The issuance of a suggested method for the determination of alkali solubility of cellulose at arbitrary sodium hydroxide concentrations is contemplated for the immediate future.

The task group on ash constituents is working more closely with the chemical methods committee of TAPPI, with the objective of establishing a single temperature for the ashing of cellulose. Joseph L. McCarthy has assumed the chairmanship of the task group on lignin, and reactivation of this work is expected shortly. The oven-drying procedure for the determination of moisture in cellulose as developed by the moisture task group was accepted as tentative by the Administrative Committee on Standards, November 10, 1954. By action of the Executive Subcommittee, a task group on sampling has been transferred to Subcommittee VI on Statistics.

Subcommittee III on Organic Esters (L. B. Genung, chairman).—The Standard Method of Testing Cellulose Acetate Butyrate (D 817 - 49), which was formerly under the jurisdiction of Committee D-20 on Plastics, is now under the joint jurisdiction of Committees D-23 and D-20, and in addition to revisions of the acetyl and butyrl test method, there is being recommended for inclusion test methods for moisture, ash, free acidity, apparent acetyl content, and viscosity.

The present Eberstadt acetyl determination method requires 24 to 48 hr for completion. The selection of a rapid acetyl method, particularly for acetone-soluble types of cellulose acetate, is being considered.

Subcommittee IV on Inorganic Esters (C. B. Gilbert, chairman).—The revised Specifications and Test Methods for Soluble Cellulose Nitrate (D 301 - 54 T) were approved by Committee D-23 and subsequently by the Administrative Committee on Standards, on November 10, 1954.

There are no new methods pending before the subcommittee at this time.

Subcommittee V on Cellulose Ethers (R. S. Apple, chairman) completed methods for testing methyl cellulose and submitted them for publication as tentative.

Agreement on a method of assaying the purity of sodium carboxymethylcellulose has not been achieved and work is continuing. However, essential agreement has been reached on methods for degree of substitution, viscosity, sodium chloride content, sodium glycolate content, and sodium phosphate content, and these are being recommended for publication as information only at this time.

Subcommittee VI on Statistics (E. J. Delate, chairman) is available for consultation by other subcommittees to set up design experiments and interpret data. It is assembling a Statistics Manual, to include a bibliography of papers and textbooks on quality control and statistics.

This report has been submitted to letter ballot of the committee, which consists of 48 members; 35 members returned their ballots, of whom 34 have voted affirmatively and 0 negatively.

Respectfully submitted on behalf of the committee,

F. A. SIMMONDS,
Chairman.

W. W. BECKER,
Secretary.

APPENDIX I

PROPOSED METHOD OF TEST FOR VISCOSITY OF SODIUM CARBOXYMETHYLCELLULOSE[1, 2]

This is a proposed method and is published as information only. Comments are solicited and should be addressed to the American Society for Testing Materials, 1916 Race St., Philadelphia 3, Pa.

Scope

1. This method of test is intended for the determination of viscosity of 1 per cent and 2 per cent aqueous solutions of anhydrous sodium carboxymethylcellulose at 25C. The practical range of this test is from 10 to 10,000 centipoises.

Apparatus

2. (*a*) *Viscometer.*—Brookfield[3] type.

NOTE.—The viscometer must be checked at frequent intervals against U. S. Bureau of Standards viscosity standards of the same viscosity range as the samples tested.

(*b*) *Constant Temperature Water Bath,* adjusted to 25.0 C and capable of maintaining this temperature within ±0.2 C.

(*c*) *Thermometer.*—An ASTM Saybolt Viscosity Thermometer having a range of 19 to 27 C and conforming to the requirements for thermometer 17 C, as prescribed in ASTM Specifications E 1.[4]

(*d*) *Sample Container.*—Wide-mouth glass jar having outside dimensions of approximately $6\frac{3}{4}$ in. height, $2\frac{5}{8}$ in. bottom diameter, and $2\frac{5}{16}$ in. mouth diameter, and a capacity of approximately 470 ml.

(*e*) *Stirring Mechanism.*—Agitator, constructed of stainless steel and conforming to the dimensions shown in Fig. 1. This agitator may be attached to any variable-speed stirring motor capable of turning up to 1500 rpm with the sample load.

(*f*) *Analytical Balance,* having a sensitivity of 1.0 mg.

(*g*) *Harvard Trip Balance* or equivalent, having a minimum capacity of 800 g and a sensitivity of 0.1 g.

Procedure

3. (*a*) Determine moisture on 5 g of the sample by drying in an oven at 105 C, to a weight loss of not more than 5 mg per 30 min drying time.

(*b*) Weigh a portion of the fresh, undried sample calculated to be equivalent to 8 ± 0.001 g of sample on an anhydrous basis for a 2 per cent solution, or 4 ± 0.001 g for a 1 per cent solution.

(*c*) Tare the sample jar on the Harvard trip balance, add approximately 100 ml water, add the sample, and then add sufficient distilled water to make 400 g total of solution. Do not stir or shake.

(*d*) Place the agitator in the solution so that the blade is approximately halfway between the bottom and the surface of the liquid. Start the stirring motor at approximately 500 rpm to avoid spilling, and increase the speed of stirring as soon

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[1] This proposed method is under the jurisdiction of the ASTM Committee D-23 on Cellulose and Cellulose Derivatives.

[2] Published as information, June, 1955.

[3] Brookfield Viscometer Model LVF or equivalent.

[4] 1954 Supplement to Book of ASTM Standards, Part 5.

as possible to 1500 rpm. Stir at this speed for 1½ hr. After this time reduce the speed so that agitation is continued at a rapid rate, but slow enough that air is not beaten into the solution. Continue stirring for ½ hr.

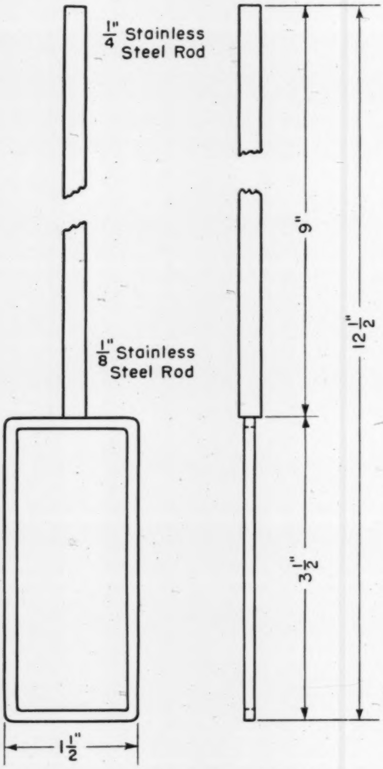

FIG. 1.—Stainless Steel Agitator.

(*e*) Transfer the sample container to the constant-temperature bath and allow to stand for 30 min. Check the temperature of the solution in the bottle with the thermometer; if not at 25.0 ± 0.2 C, allow to stand slightly longer and mix at intervals with a glass stirring rod. If the correct temperature has not been reached in 35 min, insert the stirrer while the sample is suspended in the bath and stir until the temperature is reached and allow to stand 30 min.

TABLE I.—SPINDLES AND SPEEDS.

Viscosity Range, centipoises	Spindle Number	Speed, rpm	Scale	Factor
1 to 100......	1	60	100	1
100 to 200......	1	30	100	2
200 to 500......	2	60	500	1
500 to 1 000......	2	30	100	10
1 000 to 4 000......	3	30	100	40
4 000 to 10 000......	3	12	100	100

(*f*) Remove the sample container from the bath and measure viscosity with the viscometer, selecting the proper spindle and speed from Table I. Allow the spindle to rotate until a constant reading is obtained. If the room temperature is as much as 3 C over or under 25 C, the reading should be taken while the sample is suspended in the water bath. Usually not more than 1 to 3 min is required for a viscosity measurement.

Report

4. Results should be reported as follows:

(*1*) Viscosity in centipoises at 25 C,

(*2*) Percentage of sodium carboxymethylcellulose in the test solution.

APPENDIX II

PROPOSED METHOD OF TEST FOR DEGREE OF ETHERIFICATION OF SODIUM CARBOXYMETHYLCELLULOSE[1, 2]

This is a proposed method and is published as information only. Comments are solicited and should be addressed to the American Society for Testing Materials, 1916 Race St., Philadelphia 3, Pa.

Scope

1. This method is applicable to the analysis of crude grades of sodium carboxymethylcellulose for degree of etherification.

Principle

2. The water-soluble sodium carboxymethylcellulose is converted to the insoluble acid form, purified by washing, dried, and then a weighed sample is reconverted to the sodium salt with a measured excess of sodium hydroxide.

Apparatus

3. (*a*) *Stirrer*, air-driven.

(*b*) *Buchner Funnel*, 75-mm, fitted with a 7-cm fine-texture, heavy-duty filter paper. A 60-mm, medium-porosity, fritted-glass funnel may also be used.

(*c*) *Drying Oven*, maintained at 105 C.

Reagents

4. (*a*) *Ethyl Alcohol (95 per cent by volume)*.—Denatured ethyl alcohol conforming to either Formula 2B or 3A of the U. S. Bureau of Internal Revenue.

(*b*) *Ethyl alcohol (80 per cent by volume)*.—Dilute 840 ml of Formula 2B or 3A denatured alcohol to 1 liter with water.

(*c*) *Standard Sodium Hydroxide Solution (0.3 to 0.5 N)*.

(*d*) *Standard Hydrochloric Acid Solution (0.3 to 0.5 N)*.

(*e*) *Diphenylamine Reagent*.—Dissolve 0.5 g of diphenylamine in 120 ml of H_2SO_4 (9:2). The reagent should be essentially water-white. It will give a deep blue coloration with traces of nitrate or other oxidizing agents.

(*f*) *Nitric Acid (sp gr 1.42)*.

(*g*) *Methanol*, anhydrous.

Procedure

5. (*a*) Weigh approximately 4 g of the sample into a 250-ml beaker and add 75 ml of ethyl alcohol (95 per cent). Stir the mixture with an air-driven stirrer until a good slurry is obtained. Add 5 ml of HNO_3, while agitating, and continue agitation for 1 to 2 min. Heat the slurry and boil for 1 to 2 min. **Caution.**—Care should be exercised to avoid fire. Remove the heat and continue agitation for 10 to 15 min.

(*b*) Decant the supernatant liquid through the filter, and transfer the precipitate to the filter with 50 to 100 ml of ethyl alcohol (95 per cent). Wash the precipitate with ethyl alcohol (80 per cent) until all of the acid has been removed.

(*c*) Test for the removal of acid and salts (ash) by mixing a drop of the acid carboxymethylcellulose slurry from the

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[1] This proposed method is under the jurisdiction of the ASTM Committee D-23 on Cellulose and Cellulose Derivatives.

[2] Published as information, June, 1955.

filter with a drop of diphenylamine reagent on a white spot plate. A blue color indicates the presence of nitrate and the necessity for further washing. If the first drop of reagent does not produce a blue color, further drops should be added until an excess of reagent is known to be present, noting the color after each drop: Four to six washings will usually suffice to give a negative test for nitrate.

(*d*) Finally wash the precipitate with a small amount of anhydrous methanol, and draw air through it until the alcohol is completely removed. Transfer the precipitate to a glass or aluminum weighing dish provided with a cover. Heat the uncovered dish on a steam bath until the odor of alcohol can no longer be detected (in order to avoid fires due to methanol fumes in the oven); then dry the dish and contents, uncovered, for 3 hr at 105 C. Place the cover on the dish and cool to room temperature in a desiccator.

(*e*) Weigh accurately about 1 to 1.5 g of the dried acid carboxymethylcellulose (depending on the normality of the acid and base to be used) into a 500-ml Erlenmeyer flask. Add 100 ml of distilled water and, from a buret, 25 ml of the standard 0.3 to 0.5 N NaOH solution, with stirring. Heat the solution to boiling and boil for 15 to 20 min.

(*f*) Titrate the excess NaOH, while the solution is hot, with the 0.3 to 0.5 N standard HCl solution to a phenolphthalein end point.

6. Calculate the degree of etherification as follows:

$$A = \frac{BC - DE}{F}$$

$$\text{Degree of etherification} = \frac{0.162A}{1 - 0.058A}$$

where:

B = milliliters of NaOH solution added,

C = normality of the NaOH solution,

D = milliliters of HCl required for titration of the excess NaOH,

E = normality of the HCl,

F = grams acid carboxymethycellulose used,

162 = gram molecular weight of the anhydroglucose unit of cellulose, and

58 = net increase in molecular weight of anhydroglucose unit for each carboxymethyl group substituted.

REPORT OF COMMITTEE E-1
ON
METHODS OF TESTING*

Committee E-1 on Methods of Testing held one meeting during the year at Society Headquarters in Philadelphia, Pa., on May 11, 1955.

Meetings were held of 12 E-1 subcommittees and task groups during ASTM Committee Week in Cincinnati, Ohio, January 31 to February 4, 1955. Subcommittee 17 on Thermometers and the Specifications Task Group of Subcommittee 18 on Hydrometers met in Washington, D. C., on October 7 and 8, 1954. Subcommittees 17 on Thermometers, 21 on Metalware Laboratory Apparatus, and 26 on Filtration Materials met on April 18 and 19 in New York, N. Y. Arrangements have been made for meetings of 22 subcommittees and task groups during the 1955 Annual Meeting of the Society.

Action was taken by Committee E-1 at its May meeting to organize a new Task Group on Laboratory Balances. This group will assume responsibility for the work already undertaken on performance specifications for analytical balances prepared by Subcommittee G-2 of Committee E-3 on Chemical Analysis of Metals.

The committee also authorized the organization of a Task Group on Thermal Shock Test Methods, following a survey made by a special committee earlier in the year.

Consideration is to be given to the need for undertaking work on nonelectrical thermometers such as the bimetallic type instruments. A review of this subject will be made by a special study committee.

Committee E-1 is sponsoring two symposiums on the following subjects at the 1955 Annual Meeting:

Symposium on Impact Testing, comprising two sessions on Monday, June 27.[1]

Symposium on Speed of Testing to be held on Wednesday, June 29.[1]

Plans are under way for symposiums on the following three subjects to be sponsored at future meetings:

Symposium on Tension Testing of Non-Metallic Materials, under the auspices of Subcommittee 4 on Tension Testing, for the 1956 Annual Meeting.

Symposium on Rheology, under the auspices of Subcommittee 9 on Rheological Properties, for the 1956 Annual Meeting.

Symposium on Particle Size Measurement, under the auspices of Subcommittee 11 on Sub-Sieve Testing, for the 1957 Annual Meeting.

The summary of activities of subcommittees, which is customarily included in this report, will be published this year in the ASTM Bulletin, subsequent to the Annual Meeting.

Revision of the Tentative Specifications for ASTM Hydrometers (E 100 – 54 T) will be presented to the Society after the Annual Meeting through the Administrative Committee on Standards.[2]

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* Presented at the Fifty-eighth Annual Meeting of the Society, June 26–July 1, 1955.

[1] Issued as separate publications *ASTM STP No. 176* and *No. 185*.

[2] See Editorial Note, p. 580.

This revision will comprise inclusion of detailed specifications for 27 new general purpose specific gravity hydrometers covering the range 0.645 to 2.005 in 0.001 subdivisions accurate to 0.001.

NEW TENTATIVES

The committee recommends the following two methods for publication as tentative, as appended hereto:[3]

Tentative Methods of Test for:

Young's Modulus at Room Temperature, and
Indentation Hardness of Metallic Materials by Means of Portable Hardness Testers.

REVISION OF TENTATIVES

The committee recommends that the following two tentatives be revised and continued as tentative:

Tentative Methods of Verification of Testing Machines (E 4 – 50 T):[4]

Section 1.—In the first line change "three procedures" to "four procedures" and add the following additional procedure as "C" and reletter the present procedure "C" as "D": "C. Verification by equal-arm balances and standard weights."

Section 4.—Add the following as a new Paragraph (*c*), relettering the present Paragraph (*c*) as (*d*):

> (*c*) *Verification by Equal-Arm Balance and Standard Weights.*—The third method of verification of testing machines involves measurement of the load by means of an equal-arm balance and standard weights. This method is limited to a still smaller range of loads than either of the foregoing methods and is generally applicable only to certain types of hardness testing machines in which the load is applied through an internal lever system.

Section 6.—Add the following sentence at the end of this section: "The lower limit of the loading range shall be verified by applying five approximately equal test loads, none of which shall differ from the lowest by more than 5 per cent."

Section 11.—Add the following new procedure as Section 11, renumbering the present sections accordingly:

> 11. *Verification by Equal-Arm Balance and Standard Weights:* (*a*) The balance shall be positioned so that the indenter of the testing machine being calibrated bears against a block centered on one pan of the equal arm balance, the balance being in its equilibrium position when the indenter is in that portion of its travel normally occupied when making an impression. Standard weights complying with the requirements given in Section 8 of these methods shall be placed on the opposite pan to balance the load exerted by the indenter.
>
> (*b*) Since the permissible travel of the indenter of a hardness testing machine is usually very small, the balance cannot be allowed to oscillate or swing. Instead, the balance shall be maintained in its equilibrium position through the use of an indicator such as an electrical contact which shall be arranged to indicate when the reaction of the indenter load is sufficient to lift the pan containing the standard weights.
>
> (*c*) Using combinations of fractional weights, both the maximum value of the dead weight load which can be lifted by the testing machine indenter load during each of ten successive trials, and the minimum value which cannot be lifted during any one of ten successive trials shall be determined. The correct value of the indenting load shall be taken as the average of these two values. The difference between the two values shall not exceed 0.5 per cent of the average value.

Section 14.—Add the following as a new Paragraph (*b*), relettering the present Paragraphs (*b*) and (*c*) as (*c*) and (*d*):

> (*b*) At the lower limit of the loading range the algebraic difference between the highest and the lowest percentage error of the five test loads shall not exceed 1.0.

Tentative Methods of Verification of Calibration Devices for Verifying Testing Machines (E 74 – 50 T):[4]

Section 1.—In the last sentence change "three methods" to "four methods," and add the following as the third method: "Equal-arm balances and standard weights."

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[3] The new tentatives appear in the 1955 Book of ASTM Standards, Parts 1 and 2.

[4] 1952 Book of ASTM Standards, Parts 1 and 2.

Section 5.—Add the following as a new Section 5 renumbering the present sections accordingly:

Equal Arm Balance

5. *Design of Balance.*—The balance shall be of the equal arm type having either stabilized pans or pans of the suspended type. The balance shall have adequate sensitivity to permit the detection of differences in weight on the two pans of 0.1 per cent of any test load applied during the verification of a machine. The error in the arm ratio of the balance shall not exceed 1 part in 10,000.

REVISION OF STANDARD AND REVERSION TO TENTATIVE

The committee recommends that the Standard Methods of Test for Rockwell Hardness and Rockwell Superficial Hardness of Metallic Materials (**E 18 – 54**)[5] be revised and reverted to tentative, as appended hereto.[6] In the revised method the sections dealing with equipment requirements and general information for the user are separated from those covering the test procedure and calibration of the apparatus.

ADOPTION OF TENTATIVE AS STANDARD

The committee recommends the adoption as standard of the Tentative Method for Diamond Pyramid Hardness of Metallic Materials (**E 92 – 52 T**).[4]

REVISION OF STANDARD, IMMEDIATE ADOPTION

The committee recommends for immediate adoption the following revision of the Standard Specifications for ASTM Thermometers (**E 1 – 54**),[7] and accordingly requests the necessary nine-tenths affirmative vote at the Annual Meeting in order that this recommendation may be referred to letter ballot of the Society:

Bomb Calorimeter Thermometers.—Change the requirements for Thermometers 56C and 56F to read as follows:

	Thermometers	
	56C	56F
Scale error at any point when standardized shall not exceed	0.10C	0.20F
Over any interval of	2 C	5 F
Change in correction shall not exceed	0.02C	0.05F
Standardization at multiples of	2 C	2 5F

Additional revision will be recommended in the Specifications for ASTM Thermometers (E 1 – 54) subsequent to the Annual Meeting, through the Administrative Committee on Standards.[2] This further revision will comprise the inclusion of detailed specifications for six thermometers for engine testing of fuels, and changes in the specifications for antifreeze thermometers 75F and 76F.

This report has been submitted to letter ballot of the committee, which consists of 49 voting members; 39 members returned their ballots, all of whom have voted affirmatively.

Respectfully submitted on behalf of the committee,

J. R. TOWNSEND,
Chairman.

P. J. SMITH,
Secretary.

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[5] 1954 Supplement to Book of ASTM Standards, Part 1 and 2.

[6] The revised tentative appears in the 1955 Book of ASTM Standards, Part 1.

[7] 1954 Supplement to Book of ASTM Standards, Part 5.

EDITORIAL NOTE

Subsequent to the Annual Meeting, Committee E-1 presented to the Society through the Administrative Committee on Standards the following recommendations:

Revision of Tentative Specifications for:

ASTM Hydrometers (E 100 – 54 T),

Revision of Tentative Recommended Practice for:

Characteristics of Standard Carbon Arc Accelerated Weathering Unit (E 42 – 42 T), and

Tentative Revision of Standard Specifications for:

ASTM Thermometers (E 1 – 55).

The revision of Recommended Practice E 42 was accepted by the Standards Committee on December 19, 1955, and the revised recommended practice appears in the 1955 Book of ASTM Standards, Parts 4, 6, and 7. The remaining recommendations were accepted on September 15, 1955; the revised Specifications E 100 appear in Parts 3 and 5 of the 1955 Book of ASTM Standards, and the tentative revision of Specifications E 1 appears in Part 5 of the 1955 Book.

REPORT OF COMMITTEE E-2

ON

EMISSION SPECTROSCOPY*

Committee E-2 on Emission Spectroscopy held two meetings during the year: the first in Chicago, Ill., on June 17, 1954, and the second in Pittsburgh, Pa., on March 1, 1955. The Executive Subcommittee also met on these dates, as well as in New York City on September 13, 1954.

This year marks the transition between two phases of a long-range program. The first phase consisted of providing a large quantity of authoritative spectrochemical information urgently needed by industrial and government laboratories. This phase was largely completed by the publication of Methods of Emission Spectrochemical Analysis (1953), which consisted largely of suggested methods and practices, and by the circulation of additional suggested methods and practices within the committee.

The second phase of this program consists of the careful evaluation of these suggested methods and practices, to establish a coverage of the field with tentative methods. Great emphasis is being placed on cooperative test programs, and numerous task groups have been formed for this purpose.

A large number of potential methods are being considered by the subcommittees, and a number of them will be recommended as new tentatives in 1955 and 1956. A revised edition of the Methods of Emission Spectrochemical Analysis incorporating these new tentative methods is planned for 1956.

TENTATIVES CONTINUED WITHOUT REVISION

The following tentative methods, which have stood for two years without revision, were reviewed by the appropriate subcommittees, and the committee recommends that they be continued without revision:

Tentative Method for Spectrochemical Analysis of:

Tin Alloys for Minor Constituents and Impurities (**E 51 - 43 T**),

Aluminum and Aluminum-Base Alloys by the Point-to-Plane Spark Technique (**E 101 - 53 T**), and

Zinc-Base Alloys and High-Grade Zinc by the Solution—D-C Arc Technique (**E 27 - 53 T**).

ACTIVITIES OF SUBCOMMITTEES

Subcommittee I on Apparatus and Equipment (R. G. Russell, chairman).—Group 1 on Description and Specification of Spectrographic Equipment will continue its efforts to produce an authoritative report which can be used as a basis for the description and specification of equipment and apparatus in future tentative and standard methods prepared by Committee E-2.

Group 2 on Photographic Emulsions continued the cooperative testing of emulsions for spectrochemical use. The results of these tests indicate that the emphasis should be shifted from comparisons among different types, with a view towards reducing the number of types, to the evaluation of variability within types.

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* Presented at the Fifty-eighth Annual Meeting of the Society, June 26–July 1, 1955.

Group 3 on Methods of Test for Spectrochemical Equipment was organized under the leadership of Ralph M. Thiers for the purpose of developing methods of determining the characteristics of spectrographs, spectrometers, excitation equipment, densitometers, and other spectrochemical instruments and accessory equipment.

Subcommittee II on Fundamental Methods (R. W. Smith, chairman).—Group 1 on Specification of Spark Generators has been studying spark discharges in an effort to determine the best means of determining and expressing the essential parameters which define the characteristics of the spark.

Group 2 on Precision and Accuracy was reorganized under the leadership of W. J. Youden. This group is supplying directions for the specification of precision and accuracy in suggested and tentative methods and assisting task groups of other subcommittees in the design of experiments to evaluate existing methods.

Group 3 on Basic Practices in Photographic Photometry is in the process of recasting Suggested Practice E-2 SM 2-2 entitled Photographic Photometry in Spectrochemical Analysis into proper form for elevation to tentative status. As a suggested practice this method was very well received, and proposal as a tentative only awaits editorial revision.

Group 4 on Basic Practices in Photography is similarly engaged in converting Suggested Practice E-2 SM 2-1 entitled Photographic Processing in Spectrochemical Analysis to proposed tentative status. Only minor criticisms were received after publication, and this method will be proposed as a tentative method during the coming year.

Groups 5 and 7 on Basic Computations in Optical Emission and X-ray Spectrography, under the joint leadership of M. F. Hasler and J. H. Coulliette, are preparing reports which will lead to suggested or tentative methods in the near future.

Group 6 on Semiquantitative Spectrographic Methods has compiled a cooperative test program in which several suggested methods have been compared with respect to scope, reliability, and sensitivity of detection. A report of this work was given at the Pittsburgh Conference on Analytical Chemistry and Applied Spectroscopy and will be published in the ASTM BULLETIN. The work will be continued in the direction of establishing a tentative method applicable to a very wide variety of materials with conventional spectrographic equipment.

Two new task groups were organized—Group 8 on Basic Practices in Flame Photometry under V. W. Meloche, and Group 9 on Basic Practices in X-ray Emission Spectroscopy under H. F. Carl. Each of these groups is surveying its field and actively working towards the promulgation of suggested methods of potential tentative status.

Subcommittee III, Editorial (K. O. Stevenson, chairman) reviewed ten methods under preparation by other subcommittees and issued a comprehensive set of recommendations on the editorial form and substance of suggested, proposed, tentative, and standard methods and practices. This material will serve both to improve the editorial quality of and facilitate the preparation of methods. The translations service under Cyrus Feldman issued a report to committee members covering 180 spectrochemical papers. The nomenclature group headed by V. A. Fassel was reorganized and plans work on definitions of spectrochemical terms.

Subcommittee IV on Standards and Pure Materials (G. A. Nahstoll, chairman).—A comprehensive survey of the availability of spectrochemical standard samples, covering this country and several other countries, was made to gather material for a revised edition of ASTM *STP No. 58 - D*, entitled Report on Standard Samples for Spectrochemical Analysis. Publication is expected during the summer or fall of 1955. The subcommittee continued its cooperation with and advisory assistance to the National Bureau of Standards. Efforts continued toward the standardization of shapes and sizes of graphite electrodes for spectrochemical use.

Subcommittee V on Coppe·, Nickel, and Their Alloys (A. W. Young, chairman) has revised Suggested Method SM5-1 for the analysis of nickel alloys and expects to propose it for tentative status on the completion of cooperative test work in progress in cooperation with Committee B-4 on Metallic Materials for Electrical Heating, Electrical Resistance, and Electronic Applications. Three other suggested methods are under revision or test for elevation to tentative status. Seven new methods are being considered for publication as suggested methods. A report on sampling of copper-base alloys was prepared.

Subcommittee VI on Lead, Tin, Antimony, Bismuth, and Their Alloys (E. J. Dunn, Jr., chairman).—Suggested Method E-2 SM 6-3 on the spectrochemical analysis of pig leads has been tested by five laboratories with excellent results, and this method requires only editorial revision for proposal as a tentative. A proposed tentative method on the spectrochemical analysis of tin was referred back to the subcommittee when it received two negative votes on balloting by the committee. Additional precision data were obtained and a revision will be made to satisfy the reasons given for the negative votes. The subcommittee recommends that Tentative Method E 51 - 43 T be reaffirmed for another year while a revision is being prepared. A similar method, E-2 SM 6-4, but one of broader scope, is being tested cooperatively and may eventually replace or be combined with Method E 51.

Subcommittee VII on Aluminum, Magnesium, and Their Alloys (R. W. Callon, chairman) has been concentrating on the evaluation of methods by cooperative testing. A model testing program was developed and is being applied to Method E 101 - 53 T for Spectrochemical Analysis of Aluminum and Aluminum-Base Alloys by the Point-to-Plane Spark Technique. Retention of this method for another year pending editorial revision and inclusion of further precision data is being recommended. Similar test programs and revisions are in process for a number of suggested methods with the aim of elevating them to tentative status. Additional methods are under preparation for the analysis of aluminum- and magnesium-base alloys by means of photoelectric emission spectrometers.

Subcommittee VIII on Zinc, Cadmium, and Their Alloys (Alan Goldblatt, chairman) is engaged in a formal cooperative test of a method for the spectrochemical analysis of zinc die-casting metal and high purity zinc by a spark technique and expects to propose this method for tentative status in 1955. The subcommittee is recommending that Method E 27 - 53 T be retained as tentative for another year without modification.

Subcommittee IX on Ferrous Metals (G. E. Pellissier, chairman) expects to have four new suggested methods in time for the 1955 Annual Meeting. A proposed method for the analysis of stainless steels by means of photoelectric emission spectrometers is under preparation. Task groups have been formed for the cooperative testing of these methods.

Subcommittee X on Non-Metals (W. J. Poehlman, chairman).—The following task groups are active in the work of reviewing: (1) Alkalies, (2) Ceramics and Ores, (3) Slags, (4) Nonmetallic Materials in the Iron and Steel Industry, (5) Flame Photometric Methods, (8) Agricultural and Biochemical Methods, (10) Petroleum Products. Task Group 10 has been actively cooperating with Committees D-1 and D-2 and has submitted five methods to those committees for review.

Subcommittee XI on Titanium and Related Metals (Paul A. Leichtle, chairman) was formed to meet the growing demand and need for methods for titanium, zirconium, and other metals not within the scope of existing subcommittees. An organization meeting was held on March 3, 1955. A task group on zirconium was established under Neil E. Gordon. Liaison was established with the Watertown Arsenal Analysis Panel on Titanium.

This report has been submitted to letter ballot of the committee, which consists of 153 members; 93 members returned their ballots, all of whom have voted affirmatively.

Respectfully submitted on behalf of the committee,

J. R. CHURCHILL,
Chairman.

CYRUS FELDMAN,
Secretary.

REPORT OF COMMITTEE E-3

ON

CHEMICAL ANALYSIS OF METALS*

Committee E-3 on Chemical Analysis of Metals held one meeting during the year: at the Annual Meeting of the Society on June 16, 1954, in Chicago, Ill.

Intensive effort has continued on the preparation of new and revised methods for inclusion in the next edition of the Book of ASTM Methods for Chemical Analysis of Metals.

More active participation with other ASTM groups has been under way during the year. For example, cooperative efforts with Committee B-9 are being pursued on the analysis of metal powders. For the first time, consideration is being given to preparing methods for the analysis of gases in metals, particularly in nickel, for Committee B-4. Work on preparing standards for balance performance is being pursued with Committee E-1. The general subject of accuracy and precision of methods is being reactivated with Committee A-1.

RECOMMENDATIONS ACCEPTED BY THE ADMINISTRATIVE COMMITTEE ON STANDARDS

Subsequent to the 1954 Annual Meeting, Committee E-3 presented to the Society through the Administrative Committee on Standards the following recommendations:

Tentative Methods for:

Photometric Determination of Manganese in Steel (E 30 - 54 T),
Chemical Analysis of Ferro-Alloys (E 31 - 54 T),
Chemical Analysis of Copper-Beryllium Alloys (E 106 - 54 T), and
Chemical Analysis of Electronic Nickel, Photometric Methods (E 107 - 54 T).

Revisions of Tentative Photometric Methods for:

Chemical Analysis of Aluminum and Aluminum-Base Alloys (E 34 - 50 T), and
Chemical Analysis of Lead, Tin, Antimony, and Their Alloys (E 87 - 50 T).

The revision of Methods E 34 was accepted by the Standards Committee on December 22, 1954, and the other recommendations were accepted on October 4, 1954; all will appear in the 1956 Book of ASTM Methods for Chemical Analysis of Metals.

REAPPROVAL OF STANDARDS

The committee recommends that the following standards, which have stood without revision for six or more years, be reapproved as standard without change in substance:

Standard Methods for:

Chemical Analysis of Ferro-Alloys (**E 31 - 47**),
Sampling Ferro-Alloys (**E 32 - 42**),
Chemical Analysis of Aluminum and Aluminum-Base Alloys (**E 34 - 49**),
Chemical Analysis of Magnesium and Magnesium-Base Alloys (**E 35 - 49**),
Chemical Analysis of Brasses (**E 36 - 45**),
Chemical Analysis of Nickel-Chromium-Iron Alloys (**E 38 - 48**),
Chemical Analysis of Nickel (**E 39 - 45**),
Chemical Analysis of Copper (**E 53 - 48**),
Chemical Analysis of Special Brasses and Bronzes (**E 54 - 49**),
Sampling Wrought Non-Ferrous Metals and Alloys for Determination of Chemical Composition (**E 55 - 48**),

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* Presented at the Fifty-eighth Annual Meeting of the Society, June 26–July 1, 1955.

- Chemical Analysis of Silver Solder (**E 56 - 45**), and
- Sampling Steel, Cast Iron, Open-Hearth Iron and Wrought Iron (**E 59 - 45**).

TENTATIVES CONTINUED WITHOUT REVISION

The committee recommends that, pending further study and experience in their use, the following tentative methods be continued without revision:

Tentative Methods for:

- Chemical Analysis of Pig Lead (**E 37 - 50 T**),
- Chemical Analysis of Lead- and Tin-Base Solder Metal (**E 46 - 50 T**),
- Chemical Analysis for Aluminum in Zinc-Base Die Casting Alloys (**E 47 - 50 T**),
- Chemical Analysis for Sulfur in Special Brasses and Bronzes (**E 54 - 50 T**),
- Polarographic Determination of Lead and Cadmium in Zinc (**E 68 - 46 T**),
- Chemical Analysis of Copper-Nickel and Copper-Nickel-Zinc Alloys (**E 75 - 50 T**),
- Chemical Analysis of Nickel-Copper Alloy (**E 76 - 50 T**),
- Chemical Analysis of Antimony Metal (**E 86 - 50 T**), and
- Sampling Non-Ferrous Metals and Alloys in Cast Form for Determination of Chemical Composition (**E 88 - 50 T**).

Tentative Photometric Methods for:

- Chemical Analysis of Magnesium and Magnesium-Base Alloys (**E 35 - 50 T**),
- Determination of Cobalt in Nickel (**E 39 - 49 T**), and
- Determination of Iron in Slab Zinc (Spelter) (**E 64 - 50 T**).

Tentative Recommended Practice for:

- Photometric Methods for Chemical Analysis of Metals (**E 60 - 50 T**).

The recommendations in this report have been submitted to letter ballot of the committee, the results of which will be reported at the Annual Meeting.[1]

ACTIVITIES OF SUBCOMMITTEES

Editorial Subcommittee (J. L. Hague, chairman).—Two meetings of the editorial subcommittee were held during the year. An informal style manual was completed and approved by the subcommittee for use in preparing and editing Division E-3 methods. Further work on the style manual is anticipated in cooperation with Subcommittee 15 of Committee E-1 on Methods of Testing, which is preparing general recommendations on the form of ASTM methods for chemical analysis.

Division F on Ferrous Metals (J. L. Hague, chairman).—The division prepared the procedures for manganese in steel (E 30 - 54 T), and for the analysis of ferrotitanium and for silicon in ferrotungsten (E 31 - 54 T), mentioned earlier in the report. Supplementary procedures to adapt the methods for analysis of steel (E 30 - 52) to the analysis of silicon steels will soon be submitted to the Society.

It is expected work now under way on methods for the analysis of ferroboron, for photometric determination of nickel in steel, and for determination of magnesium in nodular iron will be completed during the coming year.

Methods for aluminum in high-alloy steel, for "combustion sulfur" in steel, for columbium and tantalum in steel, for cobalt in high-alloy steel, and for zirconium in tungsten-alloyed steels are being developed but are not likely to be completed this year. A round-robin test on the "combustion sulfur" method has shown diversity of results based on a standard factor, which is considerably improved by calculation of the results on the basis of empirical standardization. Good progress has been made in developing procedures for columbium and tantalum that will give satisfactory accuracy in the presence of alloying interferences.

Division G on General Analytical Methods (H. F. Beeghly, chairman).—Subcommittee G-1 on Reagents has consulted with interested groups on specifications and in new methods from the standpoint of reagent specifications as they are adopted.

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[1] The letter ballot vote on these recommendations was favorable; the results of the vote are on record at ASTM Headquarters.

Subcommittee G-2 on Apparatus has concluded its work on balance performance and has recommended that Committee E-1 set up a new subcommittee to consider the broader aspects of balance specifications.

Subcommittee G-3 on Common Procedures, at the request of Division N, has assumed responsibility for Recommended Practices for Photometric Methods of Chemical Analyses of Metals.

Subcommittee G-4 on Precision and Accuracy has been compiling data on the precision of current ASTM methods.

Formulation of plans for publication of analytical test and standardization data has been initiated by Division G; also, symposia are being organized to be held in conjunction with the Annual Meeting and Committee Week on subjects pertinent to the objects of the division and Committee E-3.

Division N on Non-Ferrous Metals (C. Zischkau, chairman).—Division N has organized task groups for preparation of new and revised methods for the following:

Chromium copper alloys
Fire-refined copper
Antimony by rhodamine B method
Silver solder
Electronic nickel
Copper by neo-cuproine method
Magnesium-base alloys (zirconium)
Magnesium in aluminum (Versene titration)
Zinc in aluminum and magnesium-base alloys
Aluminum in zinc
Iron in high-purity zinc
High-phosphorous in brazing filler metal

During the past year, Division N prepared the new tentative methods for beryllium copper (E 106 – 54 T) and for electronic nickel (E 107 – 54 T), the revised methods for aluminum (E 34 – 54 T) and for lead, tin, antimony, and their alloys (E 87 – 54 T), mentioned earlier in the report.

The division has completed methods for copper and lead in zinc and for aluminum in electronic nickel. Also completed are revisions of the methods for magnesium in zinc-base alloys, for antimony in white metal bearing alloys, and for copper in lead, tin, antimony, and their alloys. The division will recommend deletion of the procedures for copper by the electrolytic method from E 57 – 50 T, and of the procedure by the ferric chloride method from E 62 – 50 T.

Division M on Miscellaneous Metals (R. M. Fowler, chairman).—Development of methods for the analysis of titanium and titanium alloys is proceeding in cooperation with the Panel on Methods of Analysis of the Metallurgical Advisory Committee on Titanium. This program, under the direction of the Watertown Arsenal, is nearing completion. It is expected that methods for iron, chromium, manganese, aluminum, vanadium, tin, molybdenum, and nitrogen will be available for balloting at the June, 1955, meeting, and those for magnesium, sodium, and several other elements later in 1955. An effort will be made to include all these methods in the next edition of the Book of ASTM Methods for Chemical Analysis of Metals.

High nickel-chromium and nickel-chromium-iron methods are being reviewed. Improved methods for copper and residuals such as calcium, aluminum, and magnesium are being developed. A new method for copper in these materials should be available for balloting at the June meeting.

This report has been submitted to letter ballot, which consists of 116 members; 76 members returned their ballots, of whom 72 have voted affirmatively and 0 negatively.

Respectfully submitted on behalf of the committee,

ARBA THOMAS,
Chairman.

H. KIRTCHIK,
Secretary.

REPORT OF COMMITTEE E-4

ON

METALLOGRAPHY*

Committee E-4 has held two meetings during the past year: on June 15, 1954, in Chicago, Ill., during the Annual Meeting of the Society, and on February 1, 1955, in Cincinnati, Ohio, during Committee Week. The membership of the committee presently consists of 105 members.

ACTIVITIES OF SUBCOMMITTEES

Subcommittee I on Preparation of Samples (F. C. Hull, chairman) recommends the retention of the present Tentative Methods of Preparation of Metallographic Specimens (E 3 - 46 T) until the monumental task of complete revision has been completed.

A new and revised section on electrolytic polishing has been prepared and will become the main business of the subcommittee's deliberations at the Annual Meeting in June, 1955.

Subcommittee III on Nomenclature (P. A. Beck, chairman) has been trying to resolve the difficulties encountered in attempting to arrive at a uniform system of phase nomenclature for metallic systems. At present a summary report is being evaluated by the subcommittee. This report outlines the conclusions arrived at to date and also outlines certain alternative possibilities of nomenclature.

Subcommittee IV on Photography (S. W. Poole, chairman) is recommending the retention of Tentative Methods of Preparation of Micrographs of Metals and Alloys (E 2 - 49 T) without change.

Subcommittee V on Microhardness (W. A. Shebest, chairman) is continuing the interlaboratory tests on the effect of surface preparation. Also, a previously planned test directed toward uniform calibration of instruments has been revitalized.

Subcommittee VI on X-ray Diffraction (W. L. Fink, chairman) is currently working on the revision of the Tentative Recommended Practice for Identification of Crystalline Materials by the Hanawalt X-ray Diffraction Method (E 43 - 49 T), and it is hoped that some portions of this major revision can be completed during the year.

The subcommittee is recommending the retention without change of Tentative Method of Preparing Quantitative Pole Figures of Metals (E 81 - 54 T) and Tentative Method for Determining the Orientation of a Metal Crystal (E 82 - 49 T).

Subcommittee VII on Thermal Analysis (D. J. Finch, chairman) is recommending the retention without change of Tentative Recommended Practice for Thermal Analysis of Metals and Alloys (E 14 - 51 T) and Tentative Recommended Practice for Dilatometric Analysis of Metallic Materials (E 80 - 49 T). The subcommittee is also meeting in June to discuss additional methods of analysis preparatory to the establishment of recommended practices.

Subcommittee VIII on Grain Size (R. E. Penrod, chairman) and Section (*C*) on Non-Ferrous Grain Size (H. P. George, chairman) have held several special meetings. These have resulted in the adoption of several series of charts which will be represented in the final master method of grain size determination; agreement on the methods of reproduction of the standard photomicrographs; and the completion of thorough interlaboratory checks which currently are being made on the master prints.

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* Presented at the Fifty-eighth Annual Meeting of the Society, June 26–July 1, 1955.

The grain count phase of this work relating to brass is being conducted by a joint task group of Committee E-4 and Committee B-5 on Copper and Copper Alloys.

It is expected that, when this work is completed, there will have been established one universal method for grain size determination of metallic materials.

Subcommittee XI on Electron Microscopy (R. M. Fisher, chairman) is currently completing its work on the structures in 1087 steel and is initiating new work on 4140 steel and on cold-worked low-carbon sheet steel.

The new non-ferrous section of the subcommittee has been activated and is planning its role in the broadened activities of the group. A study of the structure of a titanium alloy has begun.

The following papers appear as Appendices I to IV of this report:[1]

"Electron Microstructures of Bainite and Tempered Martensite in Steel," by D. M. Teague and S. T. Ross.

"Decomposition of Austenite and Martensite," by A. E. Austin and C. M. Schwartz.

"X-ray Diffraction Measurement of Phase Composition: ASTM Committee XI Plain Carbon Steel Tempered Martensite Series," by W. L. Grube and D. P. Koistinen.

"The Sensitivity, Reproducibility, and Accuracy of X-ray Diffraction Measurements of Retained Austenite," by K. E. Beu.

This report has been submitted to letter ballot of the committee, which consists of 105 members; 89 members returned their ballots, of whom 81 have voted affirmatively and 0 negatively.

Respectfully submitted on behalf of the committee,

L. L. Wyman,
Chairman.

Mary R. Norton,
Secretary

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[1] See pp. 590–643.

Editorial Note

Subsequent to the Annual Meeting, Committee E-4 presented to the Society through the Administrative Committee on Standards the following recommendations:

Tentative Method for:

Estimating the Grain Size of Metals (E 112 – 55 T), and

Revision and Reversion to Tentative of:

Standard Definitions of Terms Relating to Metallography (E 7 – 27).

These recommendations were accepted by the Standards Committee on September 15, 1955, and the new and revised tentatives appear in the 1955 Book of ASTM Standards, Part 2.

APPENDIX I

ELECTRON MICROSTRUCTURES OF BAINITE AND TEMPERED MARTENSITE IN STEEL*

By D. M. Teague[1] and S. T. Ross[2]

Synopsis

A series of electron micrographs are shown representing structures obtained in SAE 1087 steel as a result of the following heat treatments:

Martensite, brine quenched from 1800 F.
Martensite tempered for 1 hr at 250, 350, 400, 500 and 600 F, respectively.
Bainite transformed at 350, 450 and 500 F.

This series is a continuation of the cooperative studies of representative microstructures carried out by Subcommittee XI of ASTM Committee E-4. Because of the very fine structures present in these specimens, electron micrographs were prepared at a magnification of 30,000 × using an improved technique. The precipitation and orientation of the very fine "epsilon" carbide and its subsequent transformation to larger cementite particles are shown as a function of temperature and time.

Electron microscopy has shown itself to be of increasing value in the study of metal microstructures. The higher magnification and increased resolution of the electron microscope makes it possible to observe more minute details directly. In steel, structures isothermally transformed at lower temperatures (bainite) have been difficult to interpret. The same is true of martensite tempered at relatively low temperatures. Although considerable indirect evidence has been accumulated, based on X-ray diffraction, hardness, and other physical measurements, the exact mechanisms are not completely clear.

Subcommittee XI on Electron Microstructure of Steel, of ASTM Committee E-4, has published four reports concerning the structures of eutectoid steel produced by tempering and isothermal transformation above the M_s temperature (**1** to **4**).[3] The specimens covered by this investigation represent structures obtained by tempering and by isothermal treatment in lower temperature ranges. The authors are indebted to the members of Subcommittee XI who have graciously given permission to report the results of this investigation. This work is intended as a continuation of the contributions of Subcommittee XI to the electron metallography of steel.

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[3] The boldface numbers in parentheses refer to the list of references appended to this paper, see p. 608.

The composition of the specimens investigated was as follows:

Carbon, per cent	0.87
Manganese, per cent	0.44
Silicon, per cent	0.17
Phosphorous, per cent	0.013
Sulfur, per cent	0.006
Nickel, per cent	0.39
Chromium, per cent	0.21

Most of the heat treatments were carried out at the U. S. Steel Research Laboratories, Kearny, N. J. The heat treatments and resulting microstructures are described in Table I. The techniques used in this study are essentially the same as those described in previous publications on this series (**3**, **5**). The specimens were mechanically polished with great care to avoid disturbed surface structure. To prevent surface tempering, the specimens were not mounted in plastic, and local heating was minimized during polishing. The specimens were etched with 4 per cent picral or picral-zephiran chloride, as indicated. A negative parlodion replica was shadowed with chromium at an angle of 30 to 45 deg from the surfaces, the higher angles being used for coarser structures.

TABLE I.—STRUCTURES INVESTIGATED AND CORRESPONDING HEAT TREATMENTS.

Structure	Heat Treatment	Rockwell Hardness, C Scale
Martensite	Austenitized 35 min at 1800 F. Brine quenched	66.0
Martensite, aged 7 yr at room temperature	Austenitized 35 min at 1800 F. Brine quenched. Aged 7 yr at room temperature.	65.0
250 F tempered martensite	Austenitized 35 min at 1800 F. Brine quenched. Tempered for 1 hr at 250 F.	65.5
350 F tempered martensite	Austenitized 35 min at 1800 F. Brine quenched. Tempered for 1 hr at 350 F.	62.5
400 F tempered martensite	Austenitized 35 min at 1800 F. Brine quenched. Tempered for 1 hr at 400 F.	60.1
500 F tempered martensite	Austenitized 35 min at 1800 F. Brine quenched. Tempered for 1 hr at 500 F.	59.1
600 F tempered martensite	Austenitized 35 min at 1800 F. Brine quenched. Tempered for 1 hr at 600 F.	53.4
Bainite and tempered martensite isothermally formed at 350 F	Austenitized 35 min at 1800 F quenched in fused salt 1 week at 350 F then brine quenched.	60.5
Partial transformation to bainite at 500 F. Remainder martensite	Austenitized 35 min at 1800 F quenched in fused salt 12 min at 500 F then brine quenched.	64.5
Bainite formed at 450 F	Austenitized 35 min at 1800 F quenched in salt 5 hr at 450 F then brine quenched.	58.0
Bainite formed at 500 F	Austenitized 35 min at 1800 F quenched in salt 2½ hr at 500 F then brine quenched.	57.4

Because of the extremely minute constituents present in many of these specimens, the micrographs were prepared at a magnification of 30,000. At magnifications significantly greater than this, the structure of the plastic replica itself becomes visible.

TEMPERING OF MARTENSITE

The progressive changes which occur when martensite is tempered were observed in a graduated series of specimens, ranging from martensite, as quenched, to martensite tempered 1 hr at 600 F. This covers the transformation from freshly quenched martensite, through the formation of "percarbides," to cementite and ferrite.

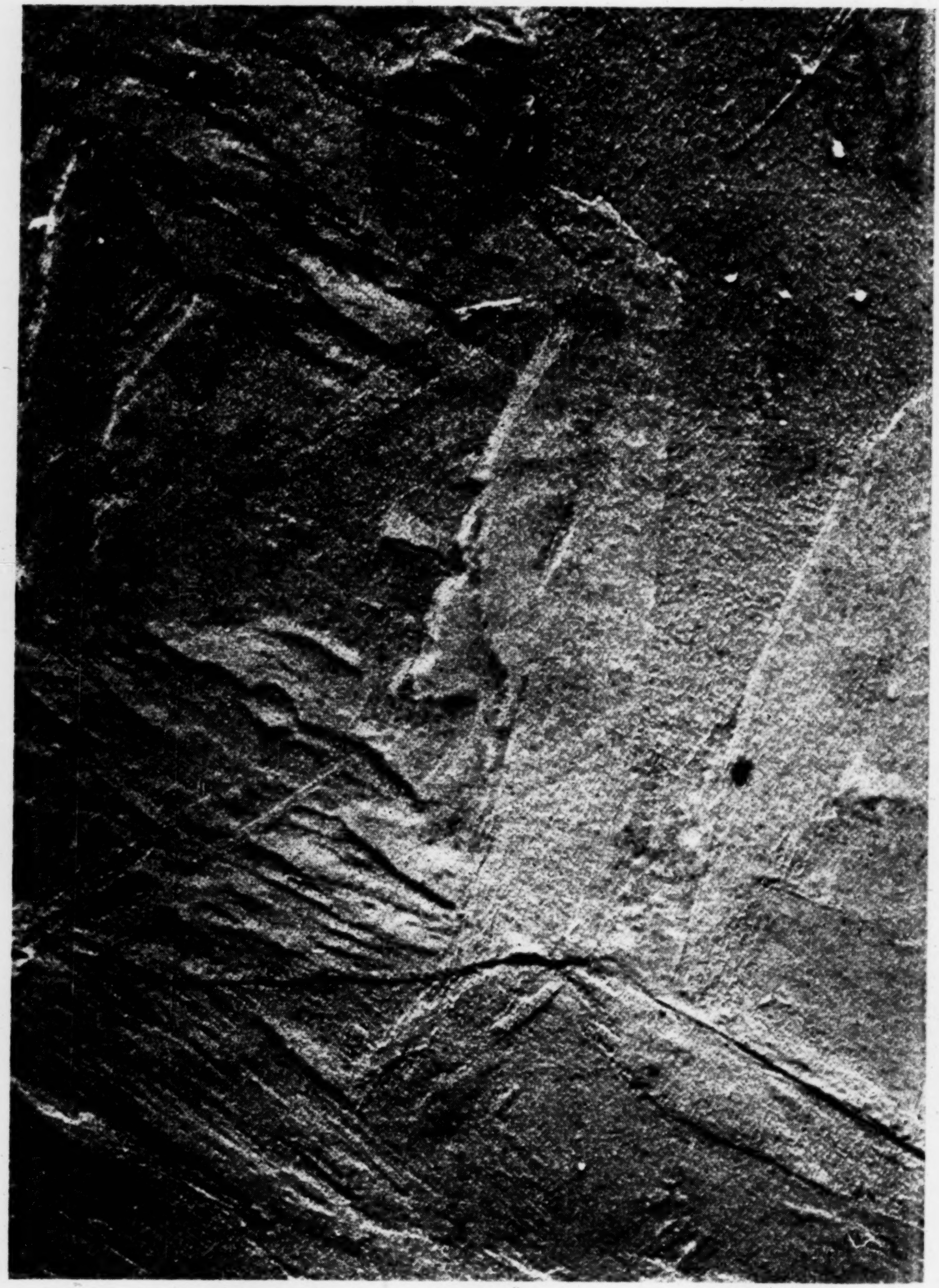

FIG. 1.—Electron Micrograph of Martensite, Brine Quenched. Picral Etch (× 30,000).

FIG. 2.—Electron Micrograph of Martensite, Brine Quenched and Aged 7 yr at Room Temperature. Picral Etch (× 30,000).

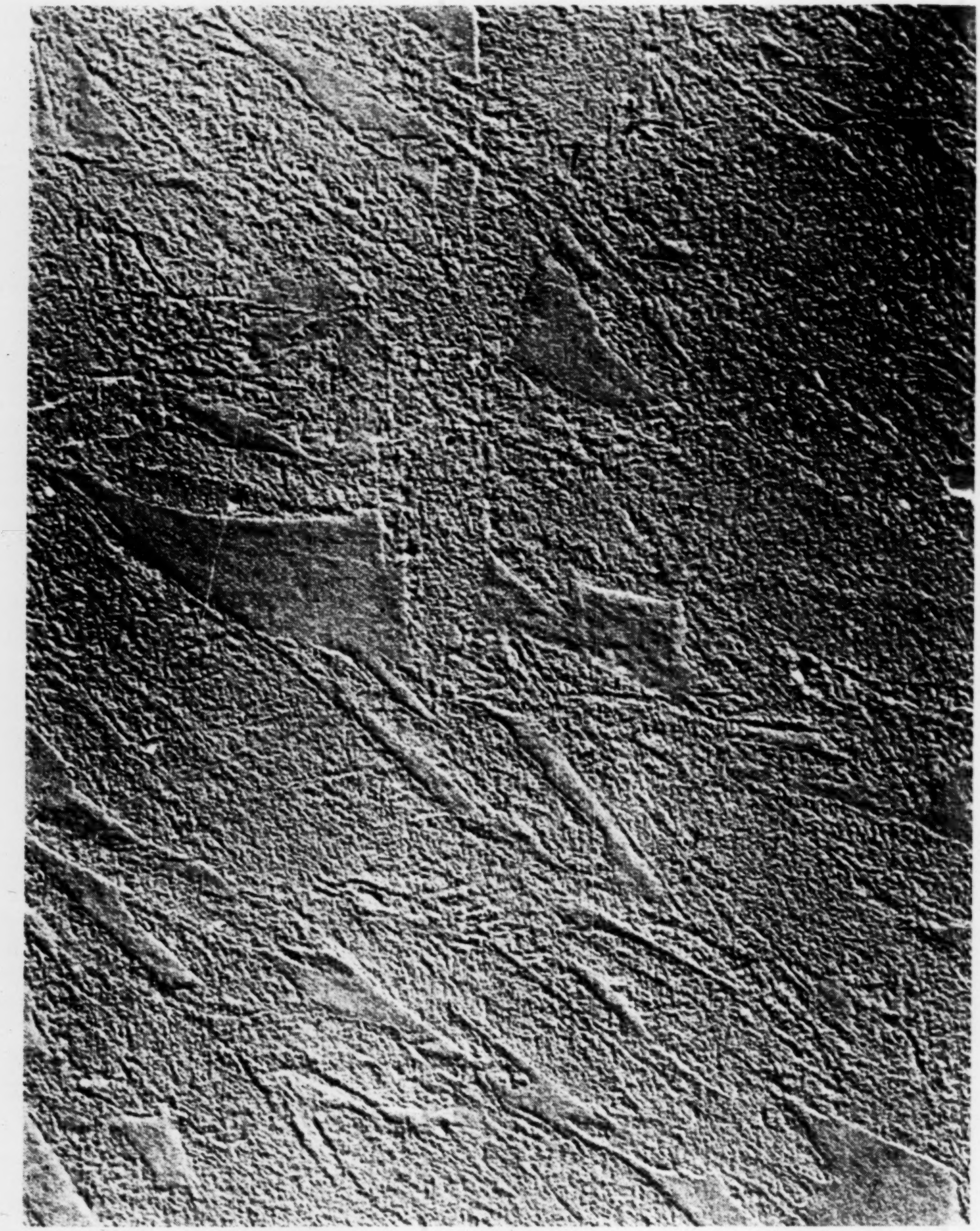

FIG. 3.—Electron Micrograph of Tempered Martensite, 1 hr at 250 F. Picral Etch (× 30,000).

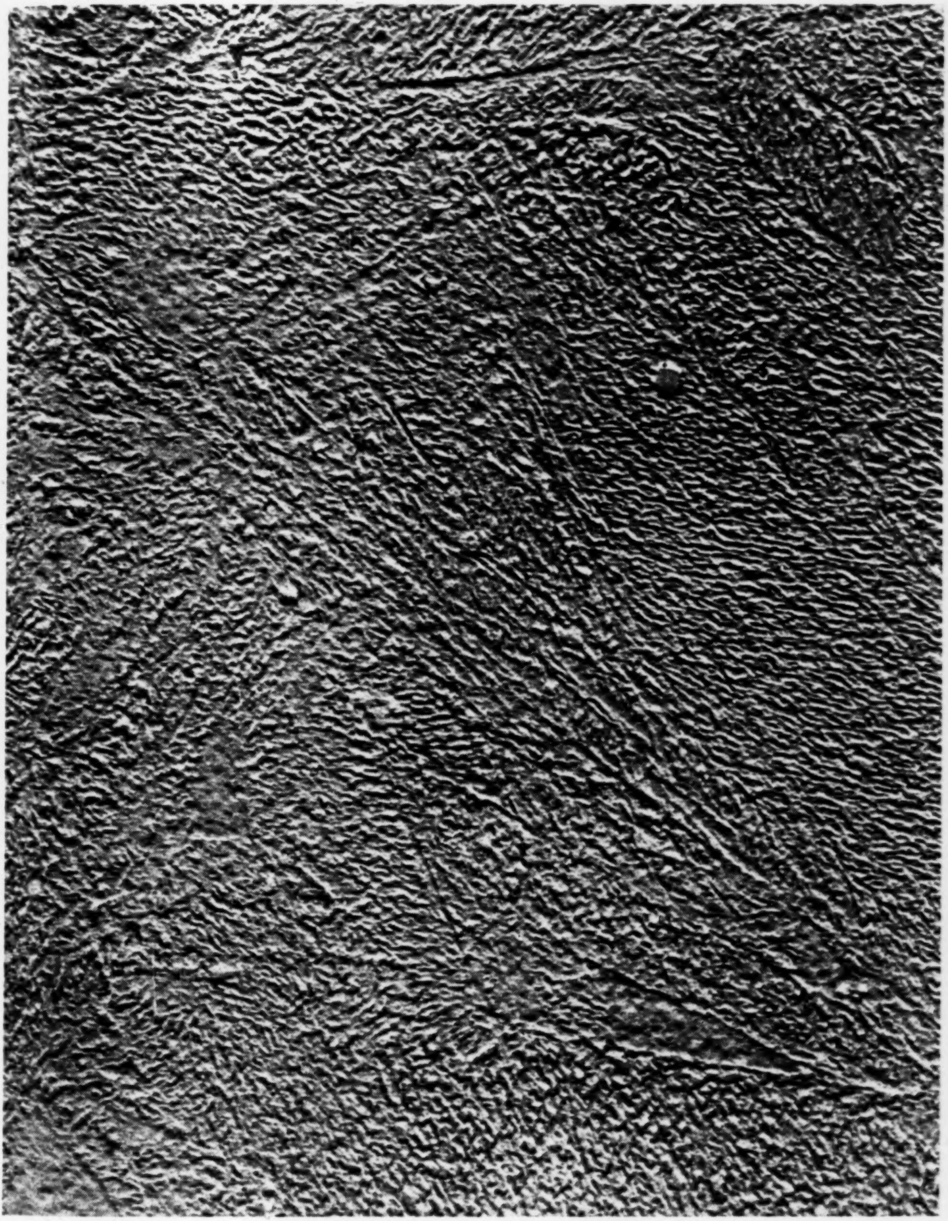

FIG. 4.—Electron Micrograph of Tempered Martensite, 1 hr at 350 F. Picral-Zephiran Chloride Etch (× 30,000).

With the eutectoid carbon steel employed here, it is well understood that a micrograph of untempered martensite is very difficult to obtain. The best practical solution to the problem was to pre-polish a thin wafer specimen and copper plate it to prevent surface decarburization. It was heated in a reducing atmosphere, quenched, in brine from the austenitizing temperature, and the copper removed. The specimen was polished a minimum amount, using ice water as coolant. It was then etched and the replicas prepared, all within a few hours.

Figure 1 is an electron micrograph of a martensitic structure so prepared. A prior austenite grain boundary is visible at the bottom of the micrograph. Although the specimen was etched for a prolonged time, the surface is generally smooth, except for acicular areas shown in relief. There is a gross 60-deg angle orientation which is also seen in martensite at lower magnifications.

According to X-ray diffraction measurements by the U. S. Steel Laboratories, identical specimens to this contain 8 to 9 per cent retained austenite. However, the typical triangular or rhombohedral areas of retained austenite are not visible here. We plan to study the structure further, using nital-zephiran chloride, an etchant which is known to show austenite better, rather than picral.

An example of the ease with which martensite becomes slightly tempered in a steel of low hardenability is presented in Fig. 2. This is a micrograph of a specimen, quenched in brine as described above, but allowed to age 7 yr at room temperature. Although the details are not entirely satisfactory, the general roughening of the surface, characteristic of tempering, is visible. The original Rockwell hardness, C scale, of this specimen was 65.1. After 7 yr at room temperature, the hardness is practically unchanged, that is 65.0.

A relatively slight amount of tempering is produced in eutectoid carbon steel by warming for 1 hr at 250 F. The decrease in Rockwell hardness is only from 66 to 65.5. Yet there is a marked change in microstructure, as illustrated in Fig. 3. There is a uniform roughening over the entire surface, excepting where retained austenite is present. The latter is readily distinguished as smooth, slightly raised areas. Measurements of several micrographs indicate about 13 per cent of retained austenite, which is slightly larger than that indicated by X-ray diffraction.

Electron diffraction patterns have been prepared from most of the specimens in this series (6). In the sample tempered at 250 F, austenite and epsilon iron carbide were identified; cementite was not present. Etching of the slightly tempered martensite reveals tiny particles in the surface, ranging from 50 to 200 Å. These tiny particles are most probably associated with the constituent that yields an epsilon carbide diffraction pattern, although we have no evidence regarding composition at this stage, and the general term "percarbide" may be more descriptive. The gross acicular pattern of martensite is quite visible.

The effect of a small increase in tempering is seen in the next specimen of the series, Fig. 4. Here, although the martensite was heated only 1 hr at 350 F, there is a considerable increase in surface roughness. The carbide phase can be identified as small particles, frequently having the appearance of minute plates. The carbide also appears as a film surrounding the martensite needles, though this is more easily observed in the next specimen of the series.

Electron diffraction patterns show epsilon carbide present, but no cementite or retained austenite. Small areas at the bottom and left of Fig. 4 show the previous location of retained austenite. Sections that had been retained austenite

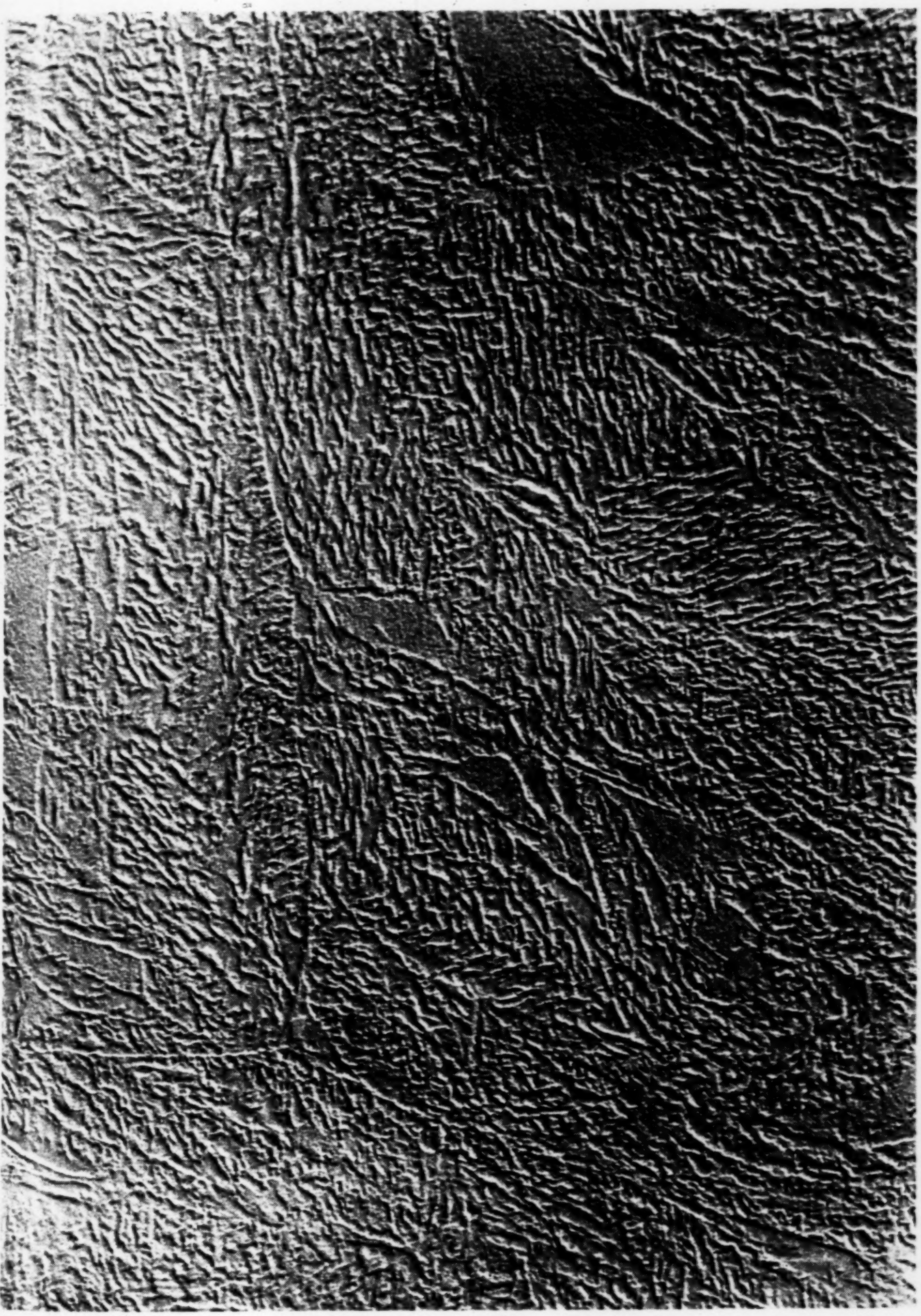

FIG. 5.—Electron Micrograph of Tempered Martensite, 1 hr at 400 F. Picral-Zephiran Chloride Etch (× 30,000).

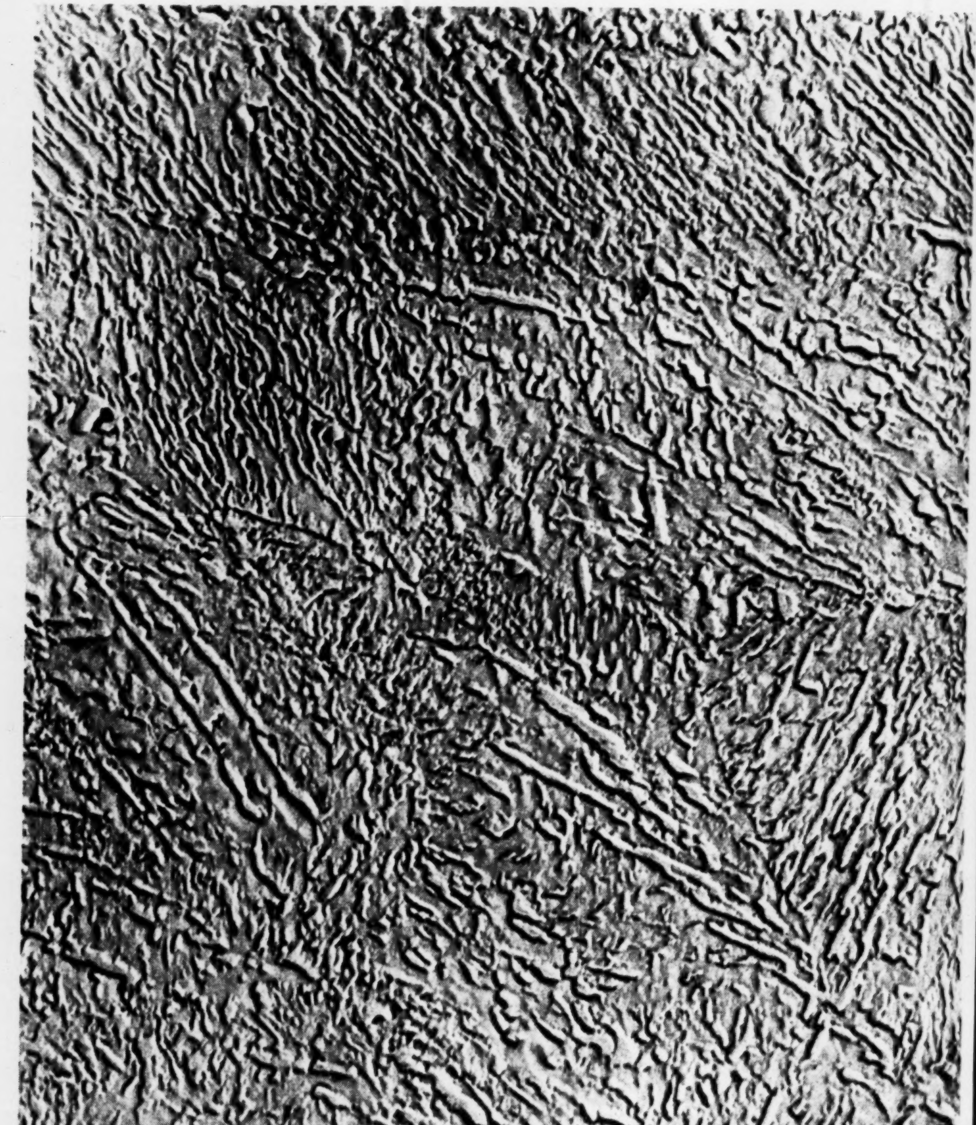

FIG. 6.—Electron Micrograph of Tempered Martensite, 1 hr at 500 F. Picral Etch (× 30,000).

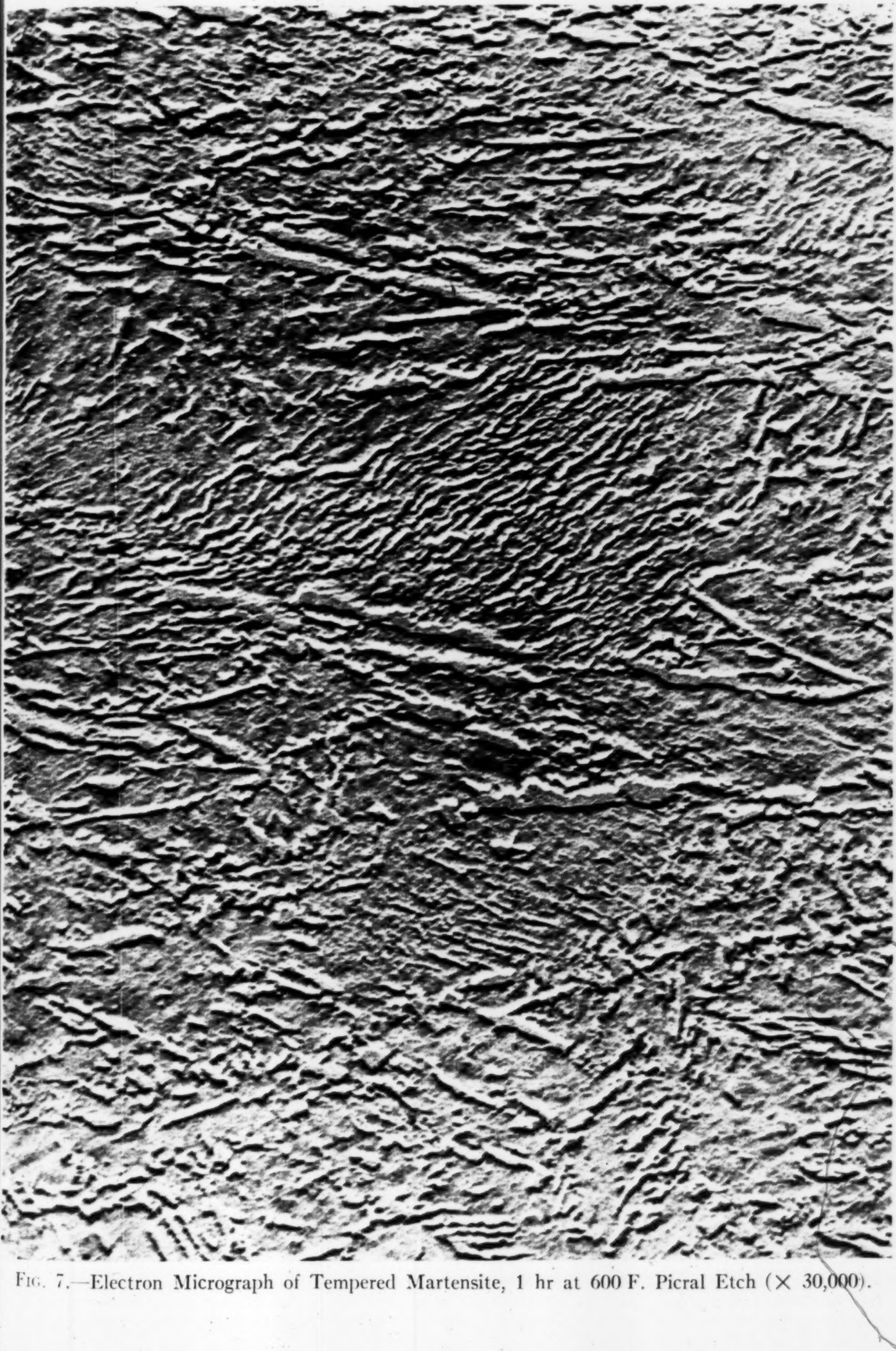

FIG. 7.—Electron Micrograph of Tempered Martensite, 1 hr at 600 F. Picral Etch (× 30,000).

are less than average in this particular micrograph. The austenite has been transformed, since the etchant attacks these areas; however the roughening is less than in the surrounding tempered martensite. No carbides are visible within the areas, and they are outlined by the carbide films surrounding adjacent needles of tempered martensite.

X-ray diffraction measurements on this series of specimens indicate that retained austenite persists even after tempering for 1 hr at 350 F or 1 hr at 400 F. Although there is evidence of some decrease in retained austenite at these temperatures, the X-ray results do not match either the visual indication of the micrographs, or electron diffraction results.

Many micrographs of this specimen resembled portions of the structure produced by isothermal transformation at 350 F (Fig. 8).

A further 50 F advance in tempering temperature, to 400 F for 1 hr, again results in a discernible change in microstructure, according to Fig. 5. The carbides are larger and fewer, and show considerable parallel orientation within specific areas. There is some resemblance to the cross-striated needles of lower bainite, except that this tempered martensite structure is finer and the oriented areas are less needle-like. No large carbides are seen; this agrees with the electron diffraction identification (**7**) of epsilon iron carbide, but no cementite, in this specimen.

Areas corresponding to austenite retained in the original martensite remain visible. They are etched but still smoother than the tempered martensite. These areas, no longer austenite, and martensite needles are seen outlined by a percarbide film.

When martensite is tempered for 1 hr at 500 F, there is a marked change, as compared with the previous specimen. There is now a duplex carbide structure, which is illustrated in Fig. 6. In some areas the carbides are large, discontinuous, and elongated and lie in the direction of the original martensite needles. In other sections, especially the left side of Fig. 6, the carbides are still small, with a parallel plate-like orientation. Since diffraction measurements indicate that both epsilon carbide and cementite are present in this specimen (**7**), it is quite probable that the large carbides are cementite and the finer carbides are as-yet-untransformed epsilon composition.

Areas that were originally retained austenite can no longer be identified, nor are the surrounding percarbide films as evident.

A further 100 F increase in tempering temperature, to martensite tempered at 600 F for 1 hr, nearly completes the transformation to cementite and ferrite. In Fig. 7 many of the carbides are very large, long, and oriented with the original martensite needles. Fine percarbides remain, though electron diffraction detects no epsilon carbide—only cementite. This is not surprising since at the glancing angle used in electron diffraction the large cementite particles in the surface will mask the fine epsilon carbide. The large cementite particles do not necessarily lie parallel to the epsilon carbide plates.

Tempering at still higher temperatures produces only a further growth of the carbide particles, and eventually a marked spheroidization (**4**). According to the series of specimens studied here, the tempering of martensite includes two phenomena:

1. The precipitation of very minute particles of epsilon iron carbide (percarbide) in ferrite, and

2. Transformation of epsilon iron carbide to larger cementite particles.

The first change occurs readily in

eutectoid carbon steel, slightly at room temperature, and noticeably after heating 1 hr at 250 F. Tempering at higher temperatures for 1 hr produces an increase in size and orientation of the tiny epsilon carbide precipitate. The second change occurs after 1 hr of tempering at 500 F, and is nearly complete at 600 F. After the transformation to cementite is complete, there is no further change at higher temperatures to Ac_3, save for an increase in cementite particle size.

According to the electron micrographs, there is no indication that the continuous phase or matrix in tempered martensite is other than ferrite, since there is no observable difference in etch attack in Figs. 6 or 7 between the matrix in the coarse cementite-containing areas, or the matrix in the fine epsilon carbide-containing areas.

The retained austenite in martensite appears to be transformed after 1 hr at 350 F but not at 250 F. No recognizable lower bainite can be seen in these areas in specimens tempered at 350 F or 400 F for 1 hr.

There is a progressive decrease in Rockwell hardness with increasing tempering temperature from C 65.5 at 250 F, C 62.5 at 350 F, to C 60.1 at 400 F. Since there is no change in microconstituents other than the transformation of retained austenite above 250 F, the loss in hardness must be principally due to the observed increase in size of the epsilon iron carbide precipitate. Tempering at 500 F and above for 1 hr results in a continued decrease in hardness, again apparently a function of the increasing cementite precipitate size.

This description of martensite tempering is in accord with the X-ray diffraction data of Jack (**8**) regarding the formation and disappearance of epsilon iron carbide. It is also in partial agreement with Lement, Averbach, and Cohen (**9**), who postulate a more detailed mechanism of tempering. These authors have also pointed out the formation of cementite films at martensitic boundaries after 1 hr at 450 F and above. The electron micrographs presented here, and electron diffraction results, indicate that these films: (**a**) form at lower temperatures, (**b**) are probably epsilon carbide, not cementite, and (**c**) gradually disappear at higher temperatures.

Isothermal Transformation Near the M_s Temperature:

The Fourth Progress Report of Subcommittee XI (**4**) indicated that epsilon carbide may also be formed during isothermal heat treatment. A group of samples, held isothermally for appropriate lengths of time at various temperatures near the M_s, was included in this investigation for purposes of comparison with tempered structures.

A specimen was held one week at 350 F in molten salt after austenitizing, and then quenched in brine in an attempt to form bainite below the M_s temperature. A bainitic-appearing needle is seen in the center of Fig. 8. It is outlined by a film of carbide and contains finely divided epsilon carbide particles in a matrix of ferrite. The microstructure is coarser and the carbides are more extensively oriented than in martensite tempered 1 hr at 350 F (Fig. 4) or 1 hr at 400 F (Fig. 5). Figure 9 is an electron micrograph at a lower magnification, 15,000 ×, of this 350 F isothermal structure and illustrates the general configuration of bainitic needles outlined by films of carbide.

Current usage implies that lower bainite is a needle-like structure of ferrite cross-striated by cementite particles. This is true of structures produced by isothermal treatment at 450 F and 500 F (Figs. 11 and 12). However, no cementite was found in this specimen either by metallographic examination at 30,000 ×

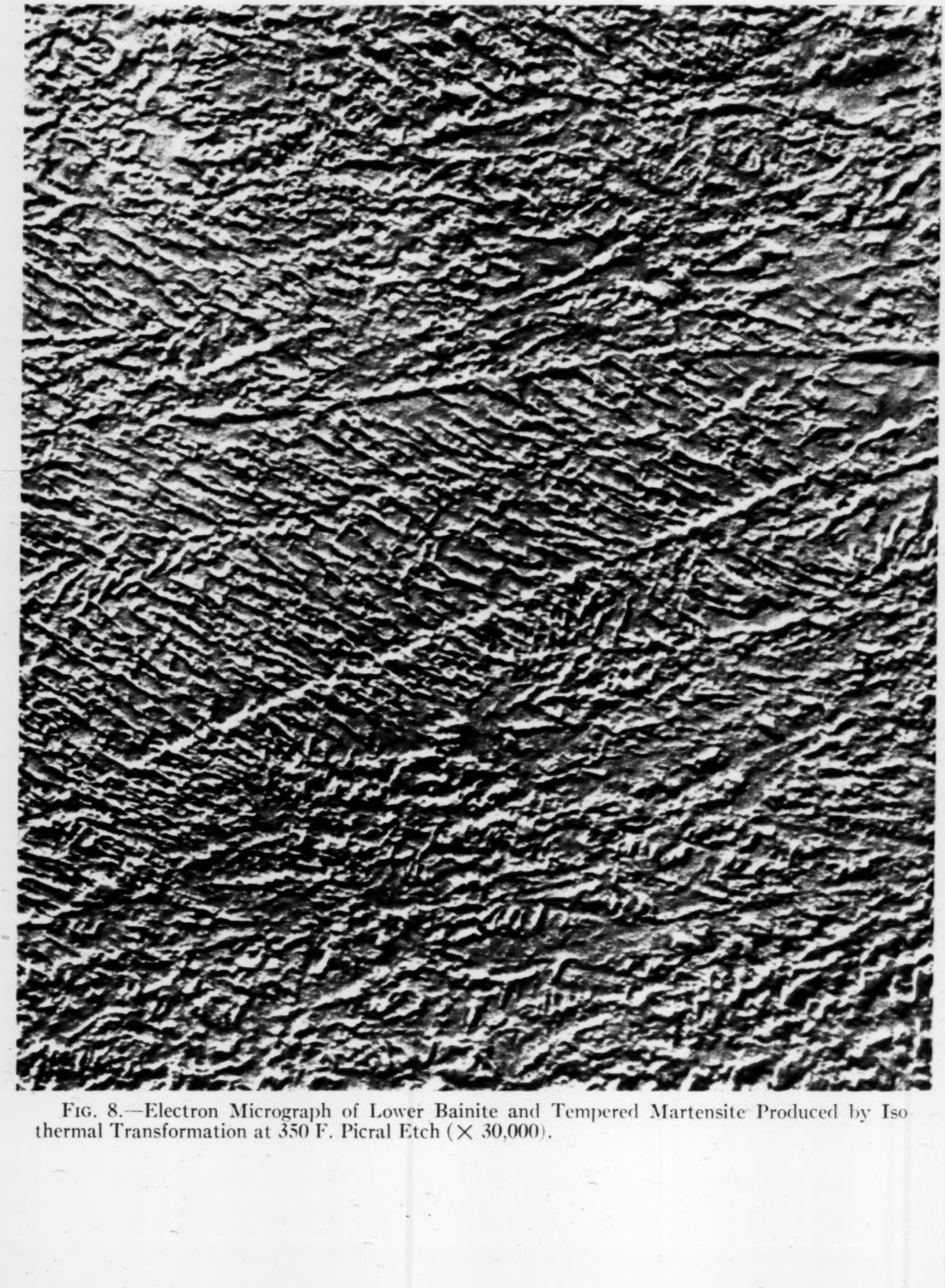

FIG. 8.—Electron Micrograph of Lower Bainite and Tempered Martensite Produced by Isothermal Transformation at 350 F. Picral Etch (× 30,000).

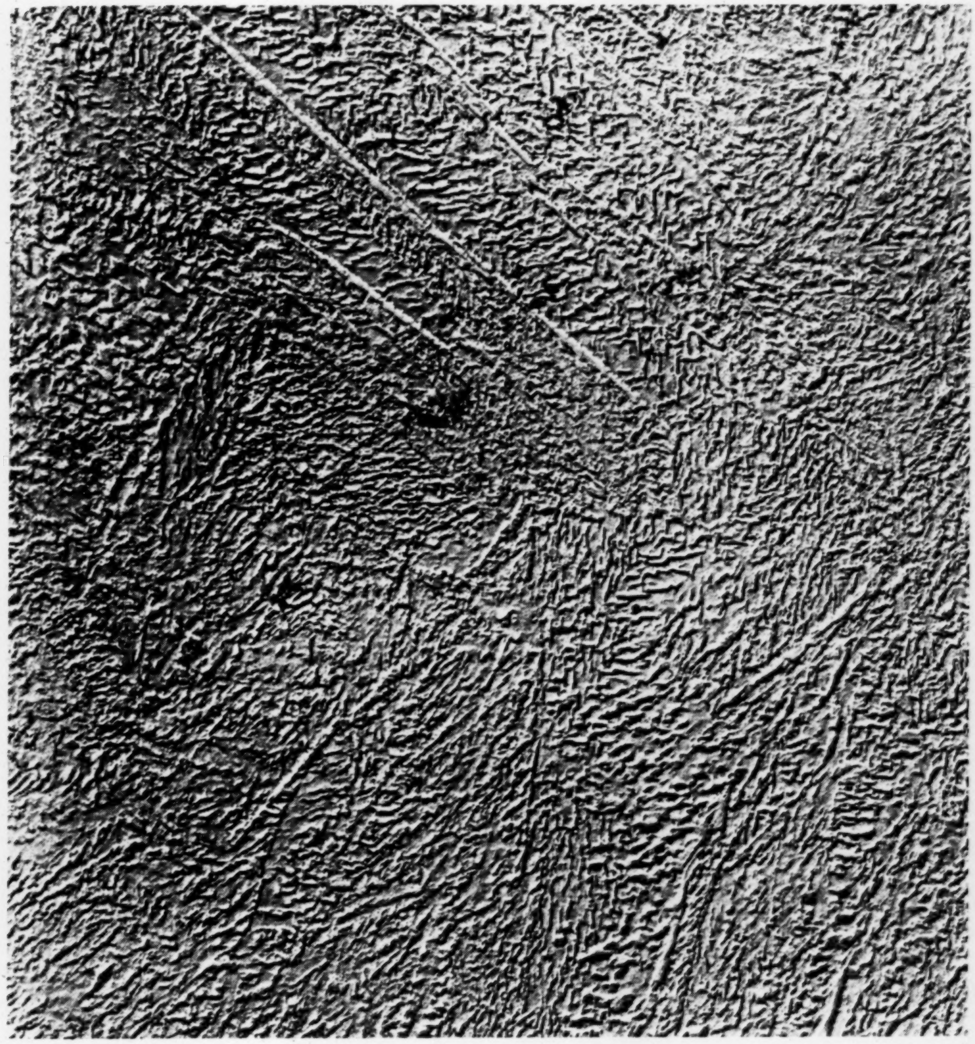

FIG. 9.—Electron Micrograph of Lower Bainite and Tempered Martensite Produced by Isothermal Transformation at 350 F. Picral Etch (× 15,000).

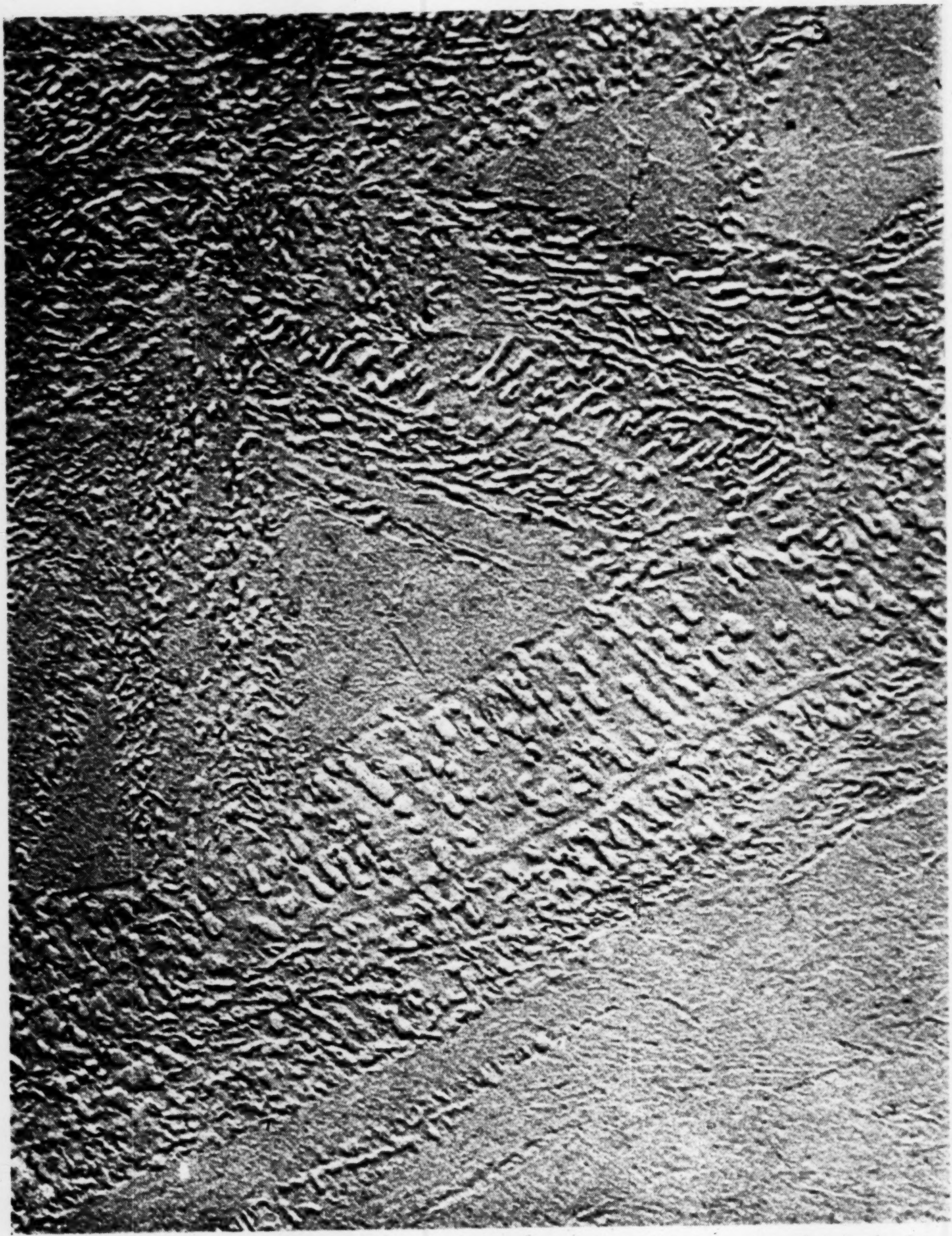

FIG. 10.—Electron Micrograph of Specimen Transformed About 20 per cent to Bainite by Isothermal Treatment at 500 F. Picral Etch (× 30,000).

or by the electron diffraction results of Austin and Schwartz (6). Thus this structure, containing epsilon carbide and no cementite, should not be properly referred to as bainite, although it is bainitic in habit.

In order to study the progressive formation of lower bainite in detail, a partially transformed specimen was prepared. The sample was austenitized, held 12 min at 500 F and quenched in brine, producing a 10 to 20 per cent transformation to lower bainite. Figure 10 shows the intersection of several bainite needles. A needle containing relatively large cementite plates in a ferrite matrix lies diagonally across the lower right. Smaller areas are visible which contain fine epsilon iron carbides, their orientation being very slight in the tinier needles. The smooth unetched structure is martensite.

Figure 11 illustrates a typical lower bainite structure formed isothermally at 450 F. It consists of needle-shaped areas cross-striated with parallel cementite plates. In addition, tiny particles of epsilon carbide are visible between the needles and in other irregularly shaped sections. Frequently, the epsilon carbide appears as very thin parallel lines like that in martensite tempered at 450 F. In other areas the particles are random. Electron diffraction confirms the presence of both epsilon carbide and cementite in this specimen.

Bainite formed isothermally at 500 F is shown in Fig. 12. A duplex carbide structure is seen, identical to that formed isothermally at 450 F. The bainite needles and cementite particles appear to be slightly larger and more elongated, while there appear to be fewer tiny percarbides. No continuous carbide films are seen surrounding oriented areas, such as are in the structure formed at 350 F (Figs. 8 and 9).

Consideration of the electron micrographs of these samples given isothermal treatments near the M_s temperature leads to two conclusions:

1. Percarbide (epsilon iron carbide) films are formed by isothermal treatment below the M_s temperature, but not above it.

2. Epsilon carbide is precipitated under the same general conditions of time and temperature, both in isothermally treated samples and in tempered martensite. The transition from epsilon carbide to cementite has a similar time-temperature relationship with either isothermal or tempering treatment.

It is difficult to place temperature limits on the changes involved in isothermal austenite decomposition and the tempering of martensite. Ross and Sernka (10) have indicated that epsilon carbide can be found as high as 800 F in SAE 1090 steel tempered for very short periods. Results of the present investigation indicate that epsilon carbide can exist in 600 F tempered martensite, even after 1 hr of tempering. Isothermal samples show that epsilon carbide is present in the initial stages of lower bainite formation. Thus, the formation and precipitation of epsilon carbide and the subsequent transformation to cementite during both tempering and isothermal treatment are time-dependent as well as temperature-dependent.

SUMMARY

Electron micrographs, supported by electron diffraction evidence, indicate that:

1. The tempering of martensite with increasing temperature consists of two changes. The first change is the progressive precipitation and parallel plate-like orientation of very minute particles of epsilon iron carbide. In eutectoid carbon

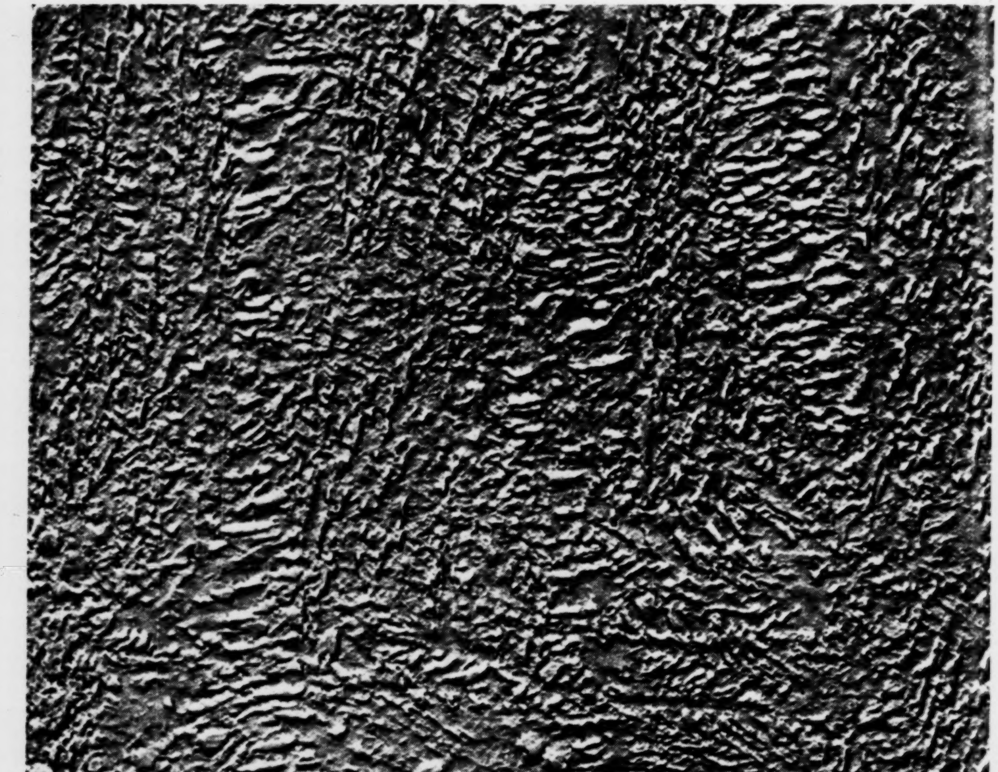

FIG. 11.—Electron Micrograph of Bainite, Isothermally Transformed at 450 F. Picral Etch (× 30,000).

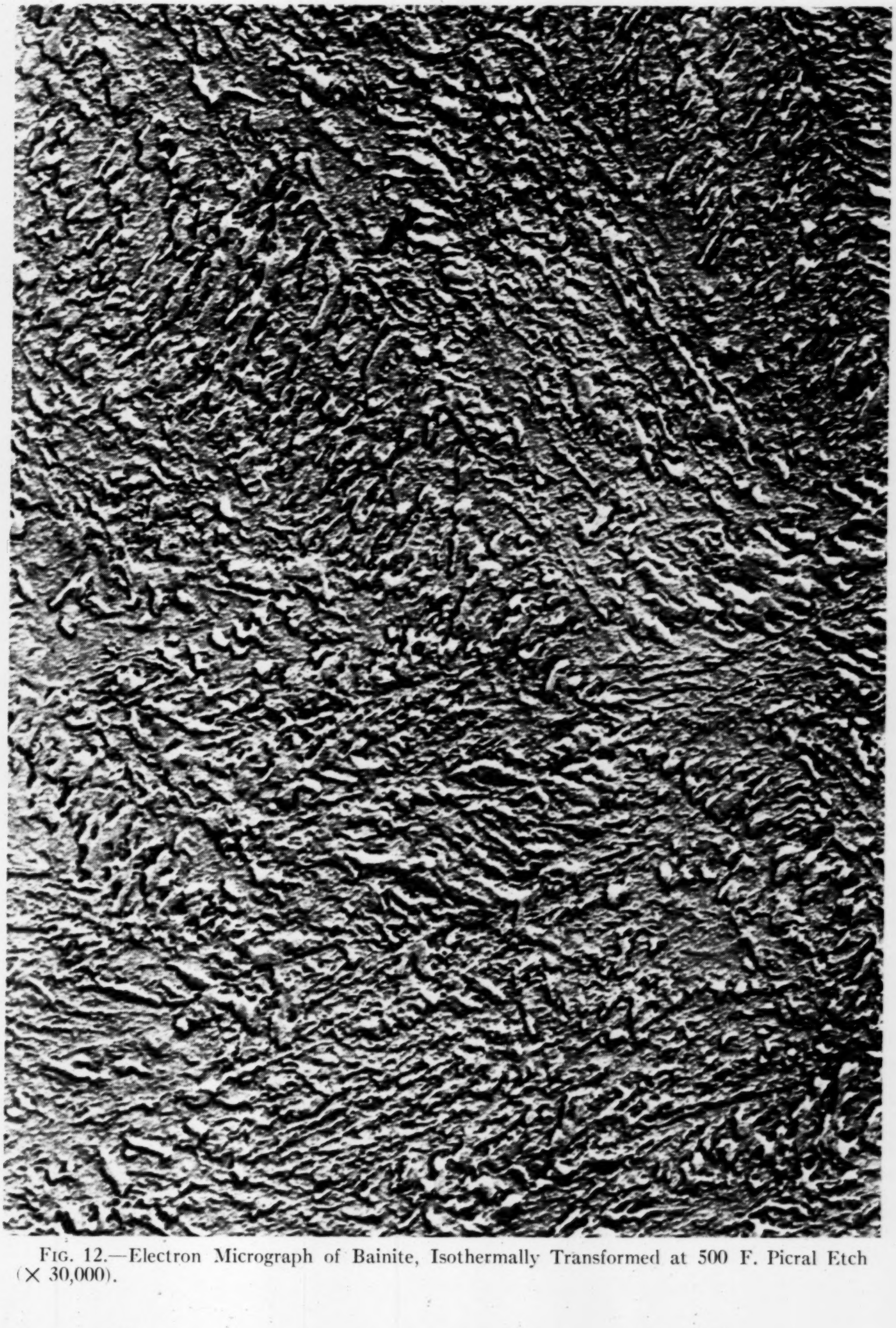

FIG. 12.—Electron Micrograph of Bainite, Isothermally Transformed at 500 F. Picral Etch (× 30,000).

steel this change begins even at room temperature. The second tempering change is the transformation of epsilon carbide to larger cementite particles. It appears after 1 hr at 500 F but is not complete after 1 hr at 600 F.

2. Films of epsilon (per) carbide are formed around acicular areas by tempering 1 hr at 350 F to 400 F. They are also formed isothermally below the M_s temperature but not above.

3. The precipitation of epsilon carbide and transformation to cementite result from similar time and temperature relationships, either in martensite tempering or isothermal transformation.

Acknowledgements:

We wish to express appreciation to Frank O. Thomas who prepared all of the electron micrographs, without which this report would not have been possible; and to R. P. Sernka for valuable technical assistance.

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DISCUSSION

Mr. C. M. Schwartz.[1] — I should like to congratulate the authors on the quality of their electron micrographs. There are some questions, however, as to interpretation of results on the basis of the electron-diffraction data obtained at Battelle Memorial Inst.

In comparing the structures of 500 and 600 F tempered martensite, the authors pointed out that although the epsilon phase was not detected by electron diffraction in the latter specimen, the micrograph (Fig. 7) shows fine carbides which look like areas in the 500 F tempered specimen (Fig. 6) known to contain epsilon. They conclude that epsilon carbide is present at 600 F, according to the electron-micrograph evidence, but is masked by the larger cementite particles at the small glancing angle used in electron diffraction. I should like to point out that although this is a possible interpretation, it is not reasonable, considering the small difference in roughness evident in Figs. 6 and 7. The electron-diffraction evidence is that the transformation from epsilon to cementite is complete between 500 and 600 F. On this basis, therefore, one should conclude that those areas of fine carbide in Fig. 7 represent epsilon transformed to cementite, which has not had sufficient time for diffusion and growth, so that the microstructure persists.

Another point is that we have detected another structure in the 250 F tempered martensite and in the room-temperature aged martensite specimens. This structure is neither that of austenite, martensite, nor epsilon. We have detected a structure of what may be this phase in electron micrographs of the 250 F specimen, using a modified etch. It appears necessary, therefore, to interpose another intermediate in the process of tempering of martensite.

Mr. D. M. Teague (*author*). — As Mr. Schwartz indicates, we had based our conclusions on the appearance of the microconstituents; assuming that the large carbide particles were cementite and the small particles were epsilon carbides. However, it is apparent that the transformation from cementite to carbide is occurring in the particular specimens mentioned. These samples may represent a condition where the fine precipitate has been transformed to cementite but had not yet agglomerated into larger particles. It would be very desirable to make a more positive identification of the carbides by extraction and identification by either X-ray or electron diffraction.

We were unable to correlate an observed microstructure with the constituent noted by Schwartz and Austin. It may be associated with the initial (lowest temperature) carbide precipitation or with the matrix during this stage. Because of this uncertainty, we called the

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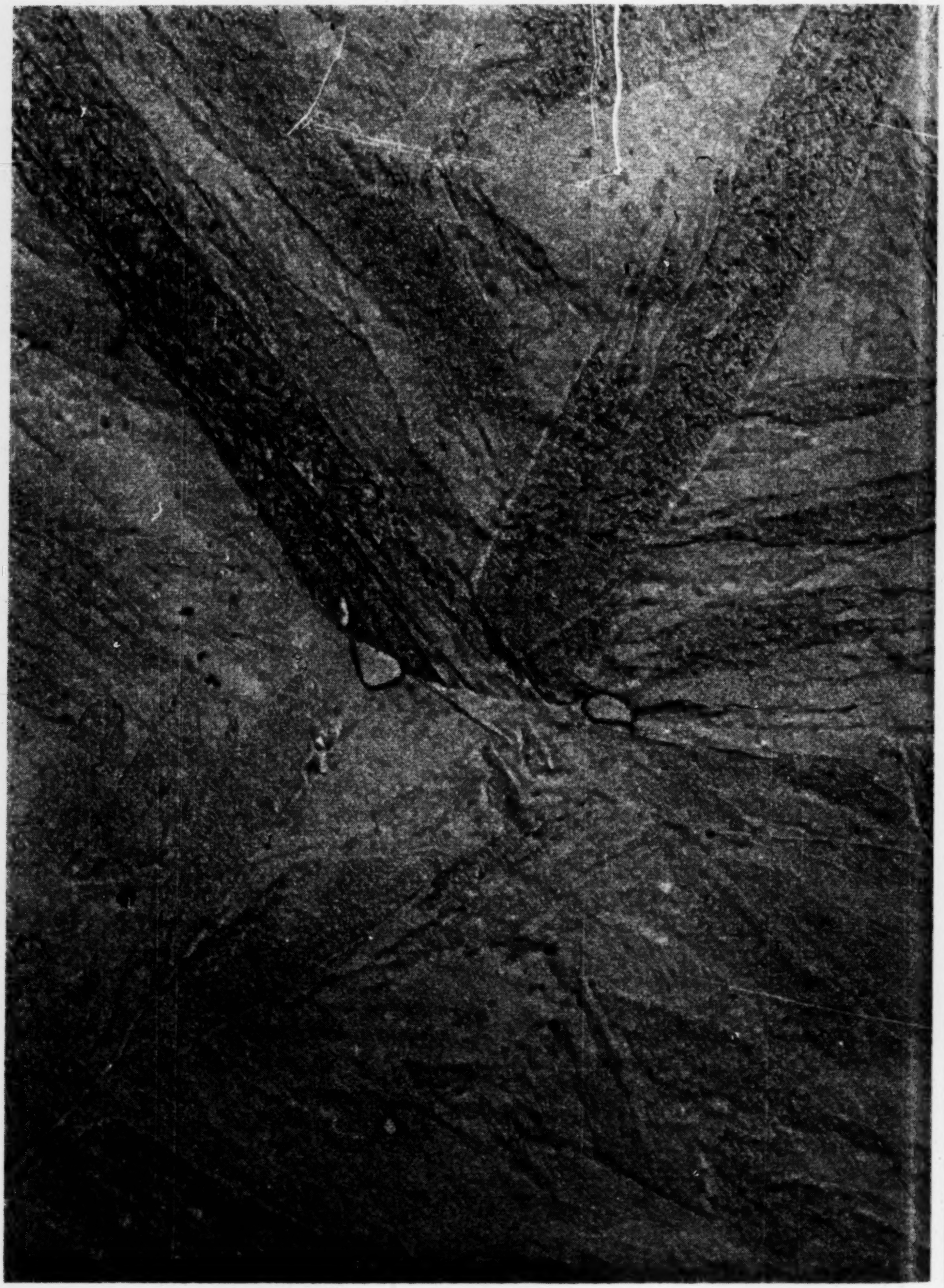

FIG. 13.—"Martensite" (× 15,000).
Electron micrograph Taken on Day of Quenching. Vilella's etch, 6 sec.

initial precipitate by the general term "percarbide".

Undoubtedly, a great deal more work remains to be done on the identification and delineation of changes occurring in the microstructures during the initial tempering of martensite. The present study is but one step in the organization of available information.

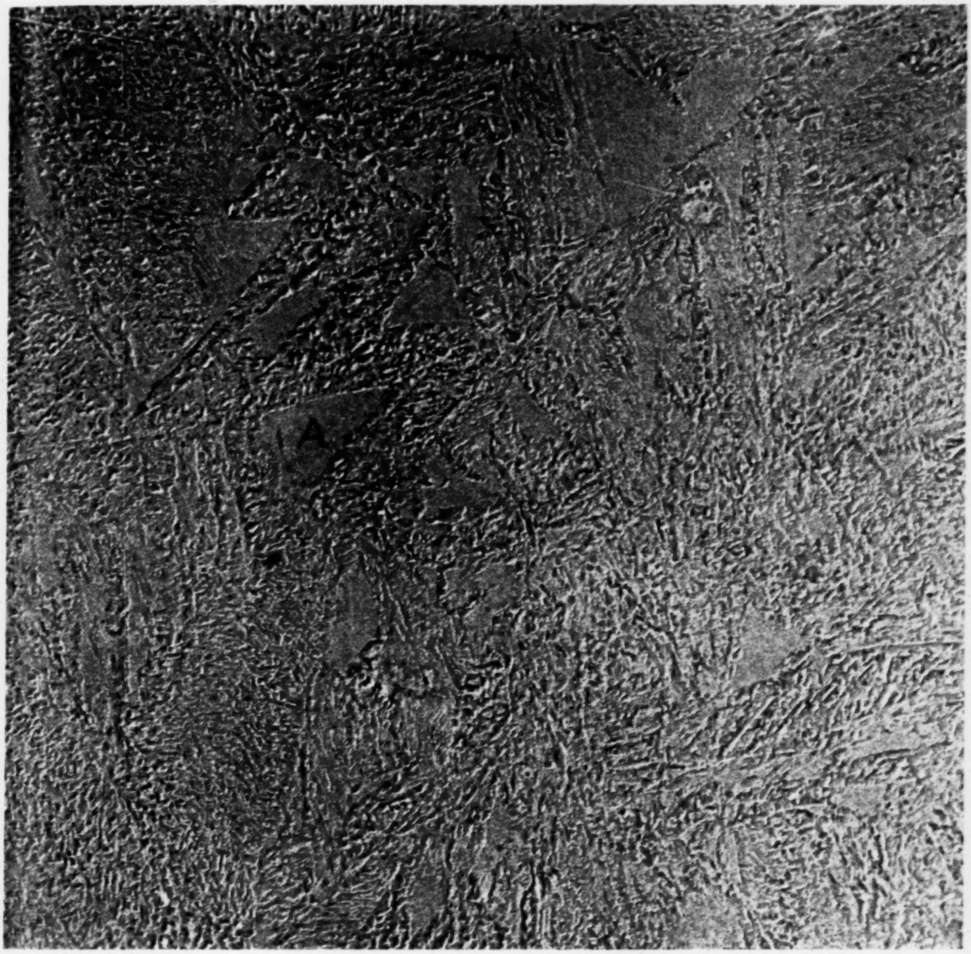

FIG. 14.—"Martensite" Aged at Room Temperature (× 15,000). Vilella's etch, 2 sec. Retained austenite "*A*".

MRS. L. DELISLE PELLIER AND MR. F. G. ROWE (*by letter*).[2]—We wish to congratulate the authors in extending and bringing to a conclusion the work of Subcommittee XI of ASTM Committee E-4 in an area in which little help can be gained from light microscopy and self reliance in electron microscopy becomes more important.

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Because of our association with the committee, we have done some work on the samples described in the paper. We have used essentially the same specimen-preparation technique, except for variations in etching, and were assisted by L. A. Siegel of this laboratory in the interpretation of some micrography with X-ray diffraction data. Our micrographs have the same general features as those of Teague and Ross and differences are usually explainable. To confirm most of the conclusions of Teague and Ross and to illustrate the degree of reproducibility obtainable by various researchers in electron microscopy, we present this discussion.

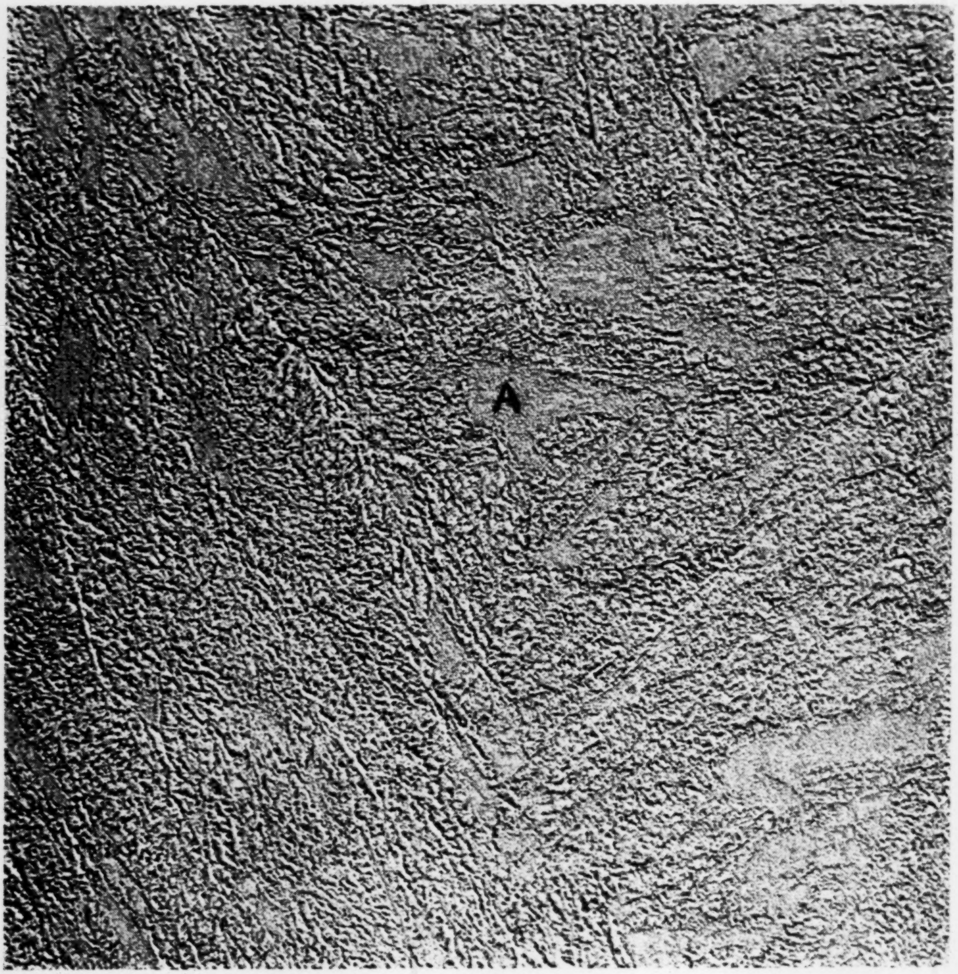

FIG. 15.—"Martensite" Aged at Room Temperature (× 15,000).
Vilella's etch, 3 sec. Longer etching makes structure more visible in retained austenite (*e.g.* "*A*").

Tempering of Martensite:

Like Teague and Ross, we observed that aging at room temperature produces a change in martensite. Figures 13

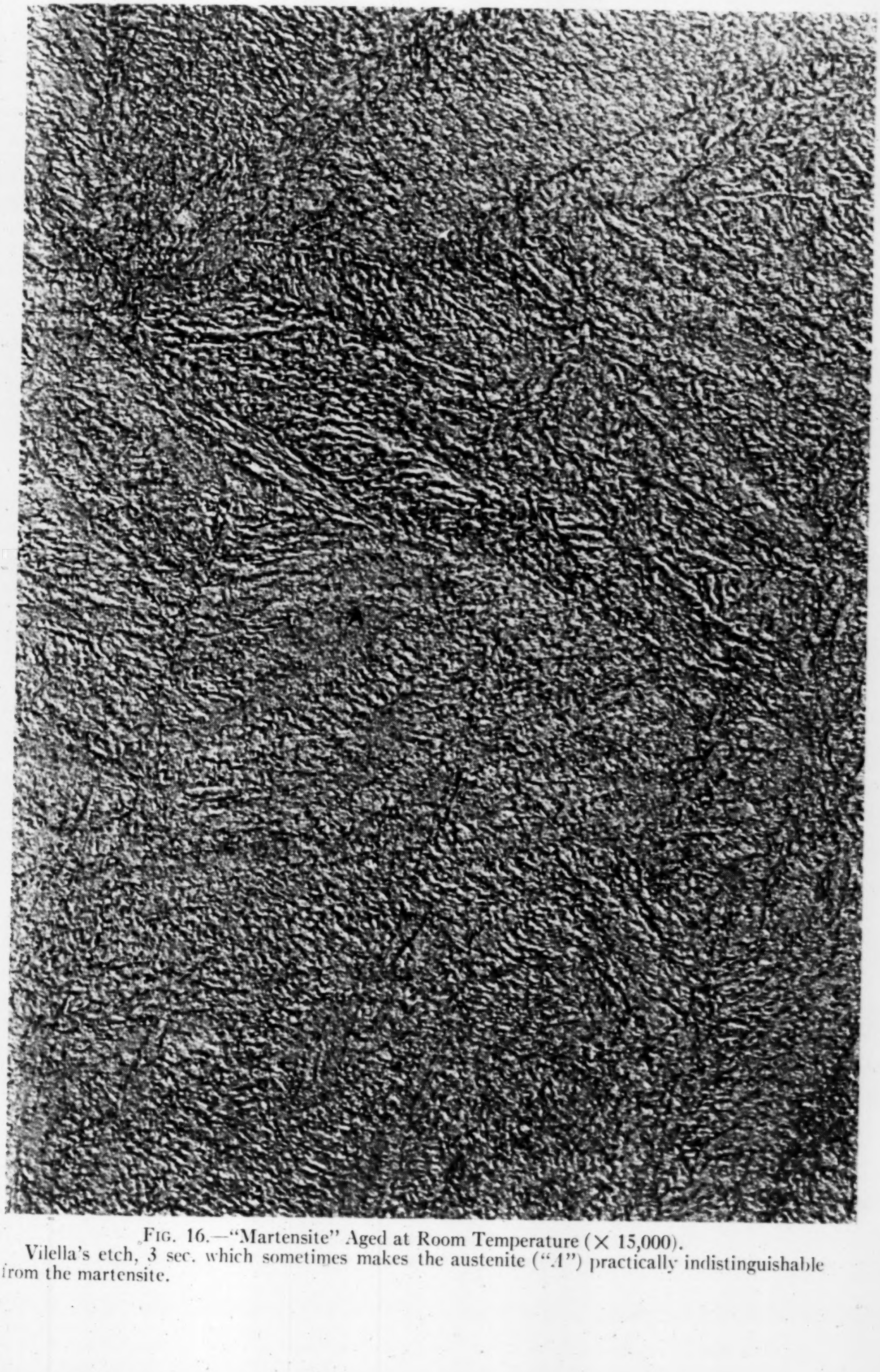

FIG. 16.—"Martensite" Aged at Room Temperature (× 15,000).
Vilella's etch, 3 sec. which sometimes makes the austenite ("A") practically indistinguishable from the martensite.

and 14 are electron micrographs of martensite, respectively, on the day it was quenched and after aging over a year at room temperature. Both specimens were polished mechanically with as much care as possible to minimize heating and distortion. In both cases the specimens were etched with Vilella's reagent, but the etching time for the former was longer (6 sec) than for the latter (2 sec). In spite of the increase in etching time, the needles in Fig. 13 show no structure or a much finer structure than those of Fig. 14. This major difference between the two structures is in agreement with the findings of the authors (see their Figs. 1 and 2). Our micrographs, however, differ in a number of respects which we are listing below together with possible explanations.

Our micrographs show:

1. Less relief in the *quenched* martensite (Fig. 13).	This may be due to the use of a different etchant.
2. More gradation in the fineness of the structure within the needles of the *quenched* martensite (Fig. 13).	The structure of the quenched martensite is so unstable that our specimen may have been tempered just slightly more than that of the authors.
3. Retained austenite in the martensite *aged* at room temperature (Fig. 14).	This may be due to a difference in depth of etch. Deeper etching brings out a fine structure in the retained austenite (that is *A*, Fig. 15). Sometimes, the austenite (*A*) becomes practically indistinguishable from martensite (Fig. 16).
4. A more sharply defined and better oriented structure in the needles of the martensite *aged* at room temperature (Fig. 14).	"Room temperature" is not a precise indication. It may allow variations in temperature sufficient to alter the degree of tempering of a structure as unstable as that of the quenched martensite.

Comparison of Fig. 3 of Teague and Ross and our Fig. 17 (both of martensite *tempered at 250 F*) shows that their results and ours are consistent; the fine structure in our micrograph appears coarser, perhaps because etching was deeper.

In agreement with Teague and Ross, we found that tempering 1 hr at 350 F produced a coarsening of the fine structure in some of the martensite needles. It also resulted in the formation of a film, perhaps a carbide, around a few of the same needles. However, in our micrograph (Fig. 18) retained austenite is still visible, and two types of fine structure in the martensite, one finer and less in relief than the other, are much more definitely brought out. Our Fig. 18 shows the most significant differences from the results of Teague *et al* (their Fig. 4). 350 F is perhaps close enough to the M_s temperature to produce a very unstable structure that can be appreciably modified by slight variations in temperature or local conditions within the samples, such as slight changes in composition or internal stresses.

A brief *X-ray diffraction study* of the samples has been carried out by L. A. Siegel of these Laboratories. Back reflection patterns were obtained from the samples of quenched martensite (on day of quenching) and martensite tempered at room temperature, 250 F and 350 F, respectively. For the first two samples only very diffuse patterns were found, while the 250 F sample showed two barely distinguishable broad rings in the vicinity of the angular region corresponding to the (220) line of ferrite. In the pattern obtained from the 350 F sample, these two rings became sharper and readily distinguishable. They can be interpreted as arising from the splitting of a cubic (220) line due to the presence of a slightly tetragonal martensitic struc-

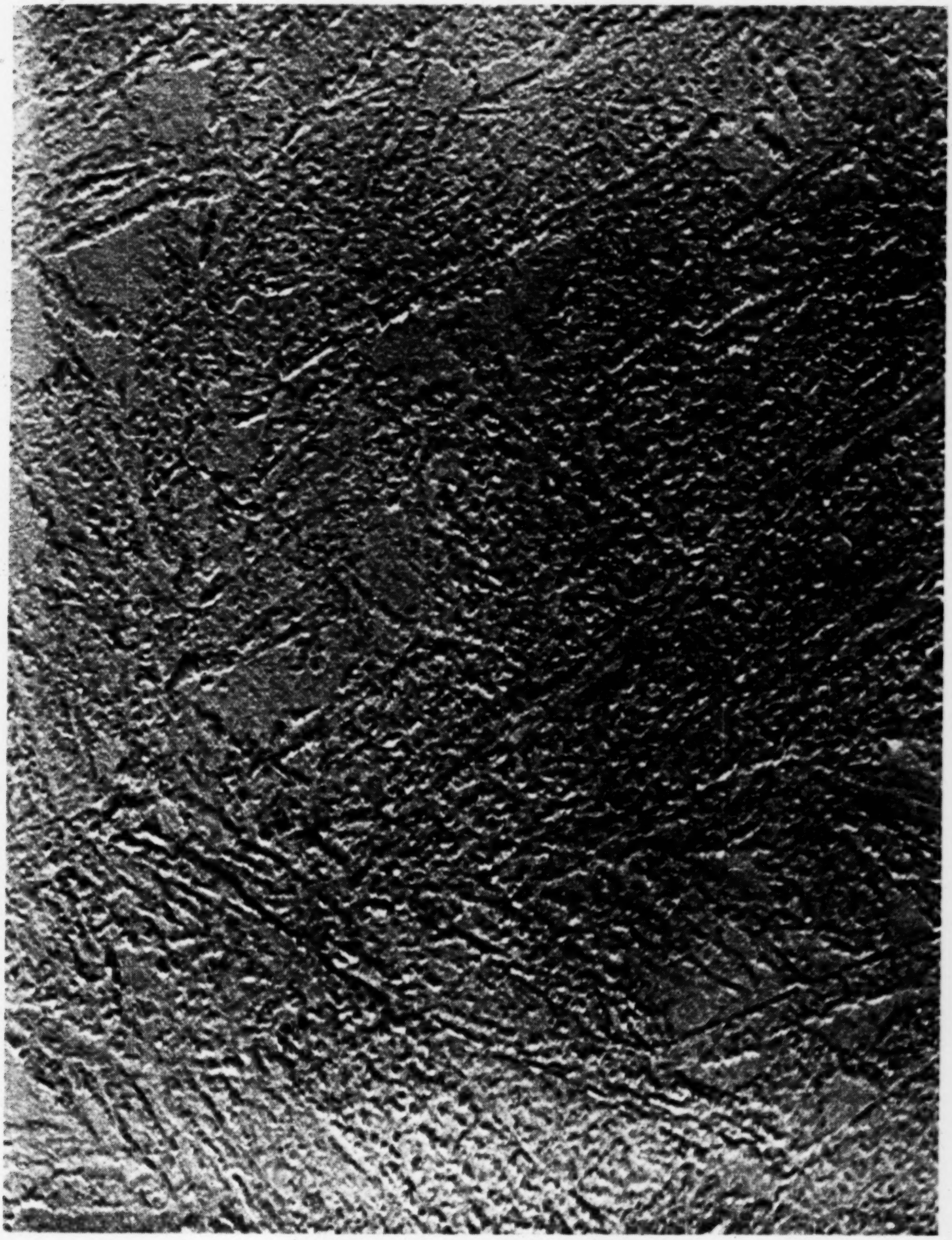

FIG. 17.—Martensite Tempered at 250 F (× 30,000).
Vilella's etch, 2 sec.

ture. Their intensities, however, are the reverse of what might be expected. This suggests the presence of an additional component adding to one of the lines.

carbides (likely cementite), and (3) persistence of some of the finer carbides.

In agreement with the authors, we found, therefore, that in the steel studied, martensite produced by quenching at or slightly below room temperature is a very unstable structure that can be tempered at room temperature. In samples tempered below the M_s temperature, a fine structure is easily shown to be present in the martensite needles. It

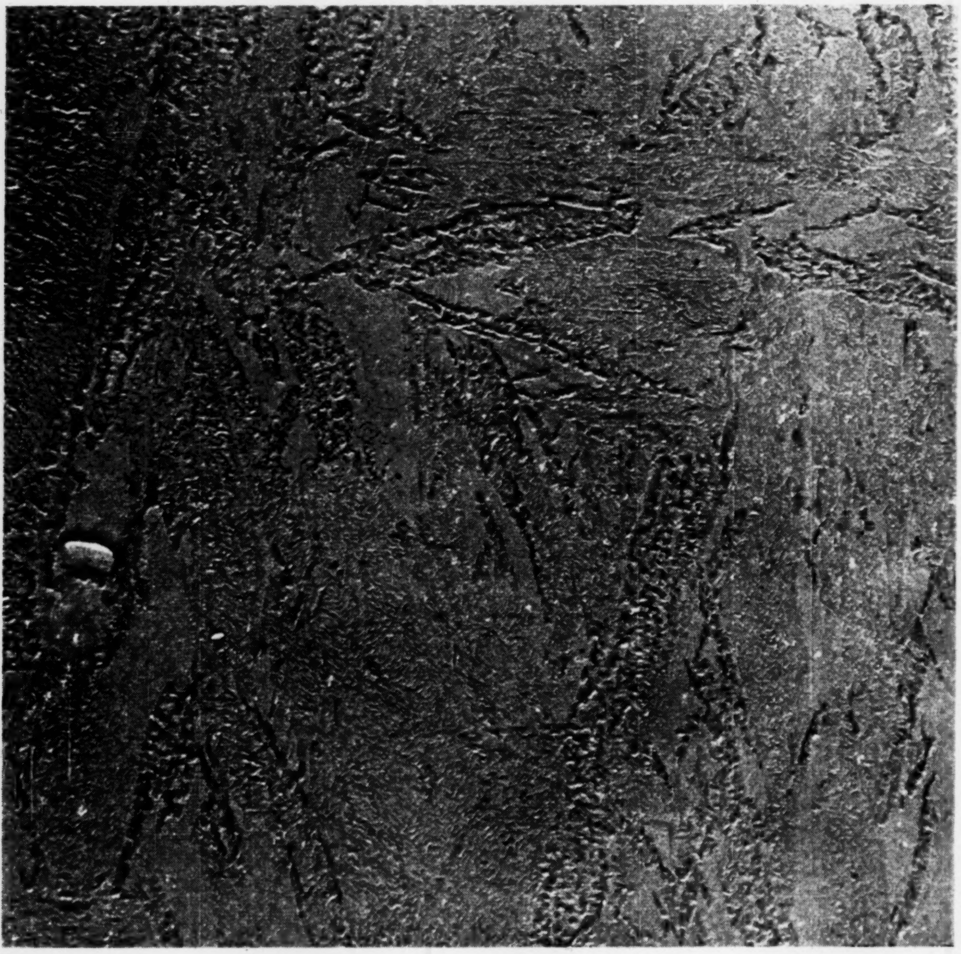

FIG. 18.—Martensite Tempered at 350 F (× 15,000).
Vilella's etch, 2 sec. Retained Austenite is still visible: Two types of Carbide appear present in Martensite Needles.

We did not do enough work on the martensite samples *tempered at 400 F and 500 F* to justify a detailed comparison. However, like Teague and Ross we observed changes with tempering at 500 F: (1) absence of retained austenite, (2) appearance of coarser elongated

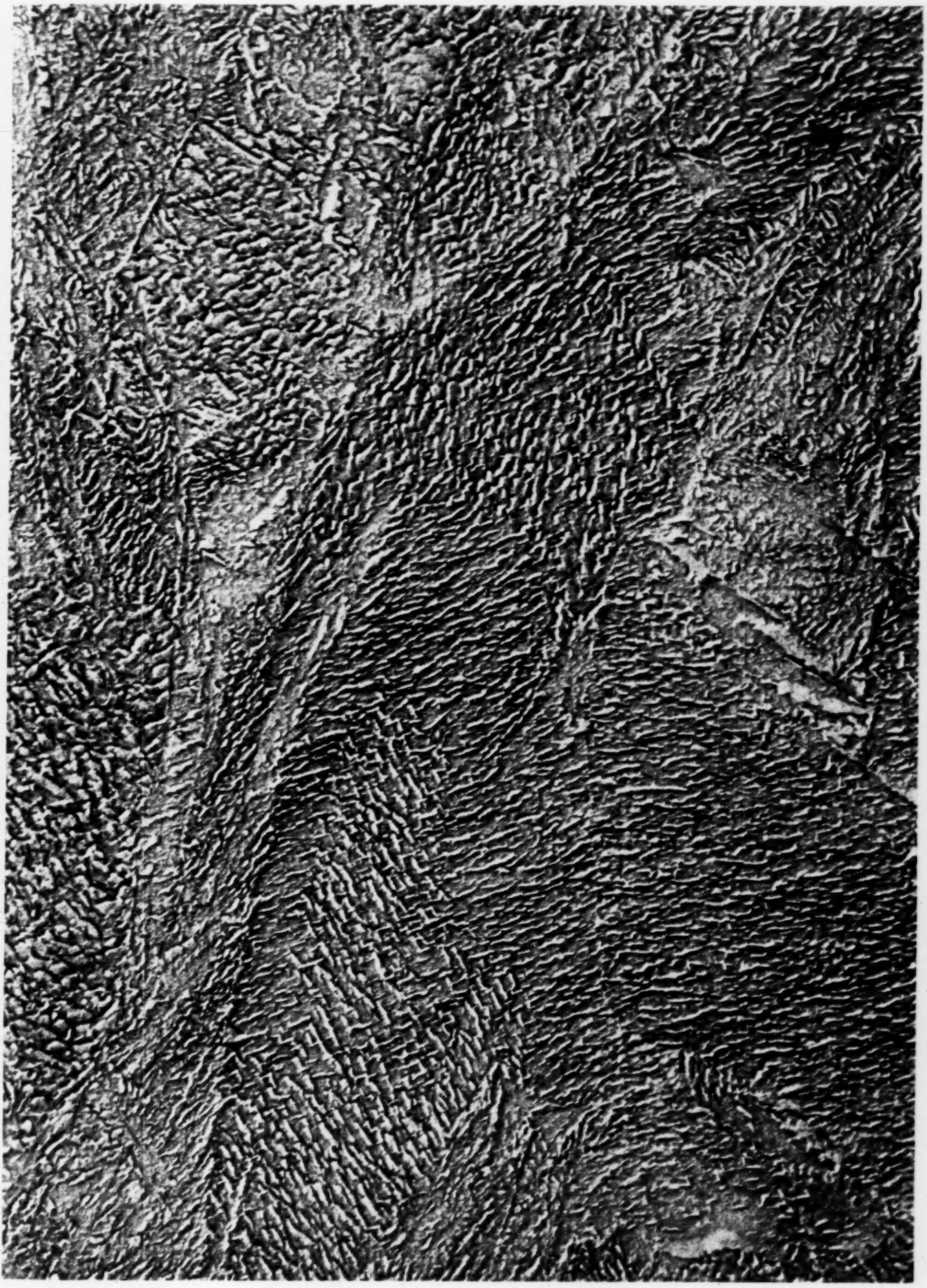

FIG. 19.—Bainite, Isothermal Transformation at 350 F (× 15,000). 4 per cent Picral etch, 4 sec. Two types of precipitate appear to be present.

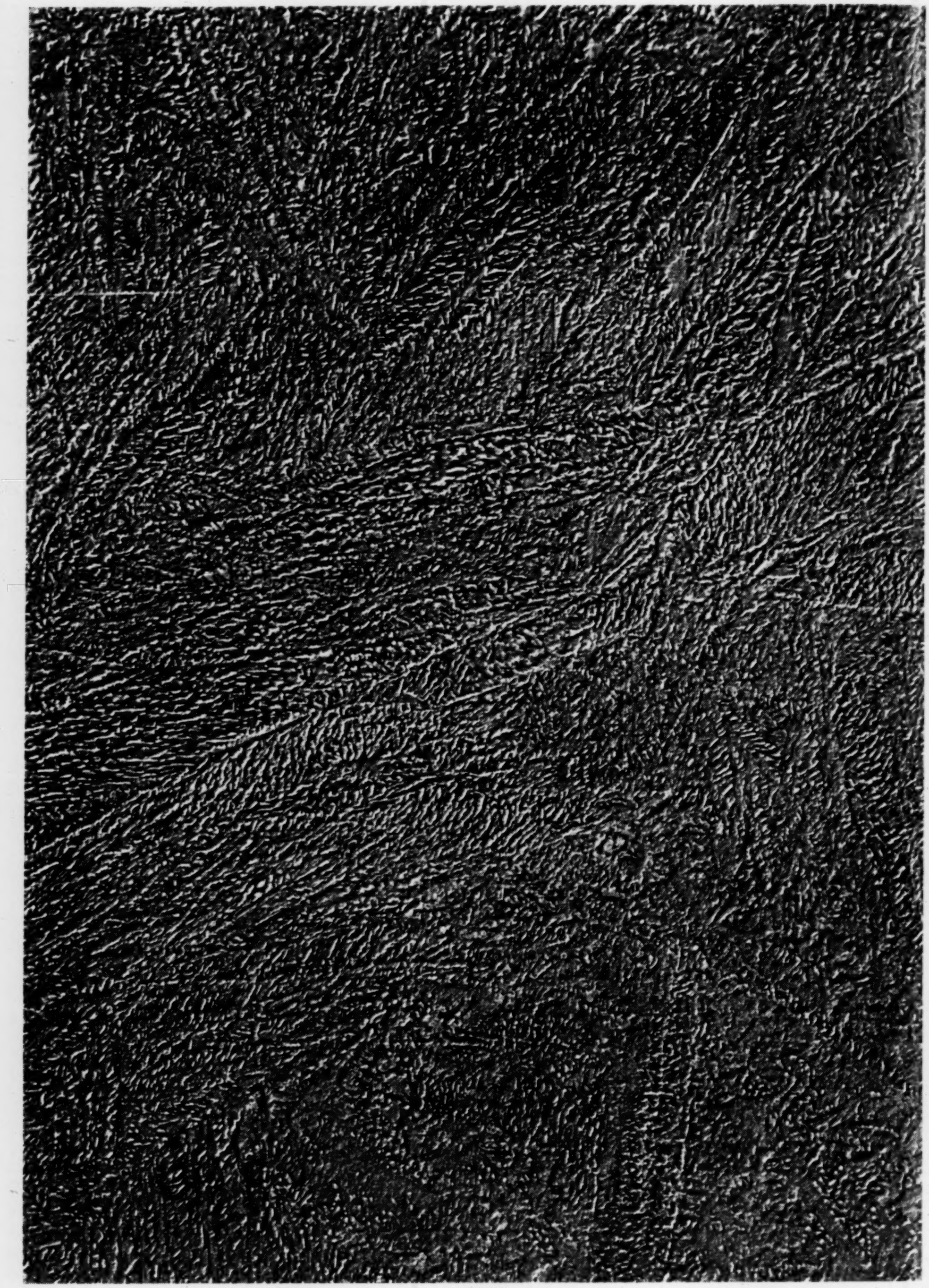

FIG. 20.—Bainite Isothermally Formed at 350 F (× 10,000).

4 per cent Picral etch, 4 sec. Lower magnification brings out general structure. Film (perhaps carbide), marked "C", around some needles.

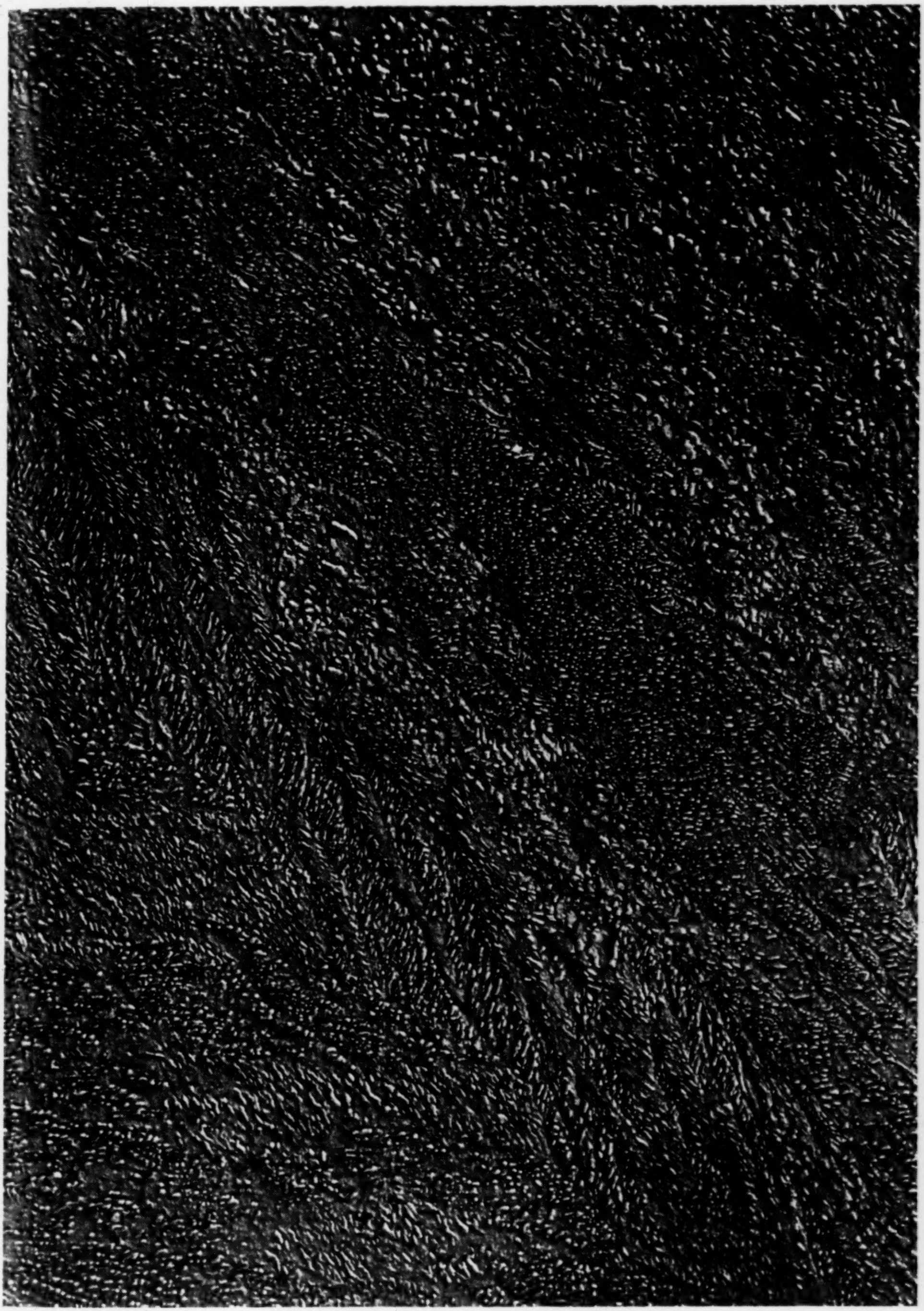

FIG. 21.—Bainite Isothermally Transformed at *500 F* (× 10,000).
4 per cent Picral etch, 3 sec. Duplex carbide structure.

is not essentially modified by tempering 1 hr at temperatures up to 400 F, except for a slight coarsening. Such a structure may be associated with the epsilon carbide shown to be present by electron diffraction (reference 6 of paper by Teague and Ross).

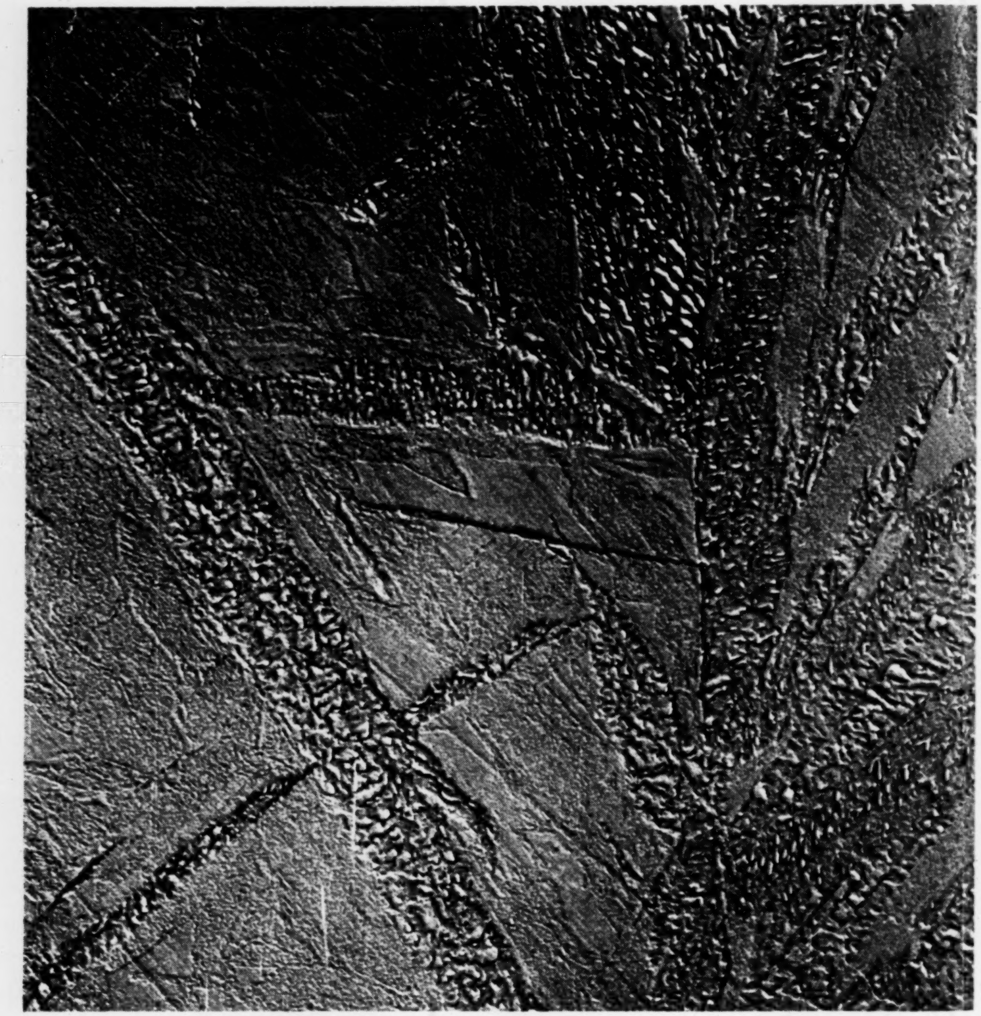

FIG. 22.—Partial Transformation to Bainite at *500 F* (× 15,000).
4 per cent Picral etch, 4 sec. Bainite Needles in Matrix of Martensite (probably tempered) and Retained Austenite.

We also found by X-ray diffraction that martensite is retained after tempering 1 hr at 350 F. The decrease in the diffuseness of the reflections with increases in tempering temperatures suggests that a recovery of the matrix accompanies the formation of the carbides. As suggested by Geisler,[3] both processes could contribute to the relief of the internal stresses resulting from the austenite to martensite transformation. Both processes could also be related since carbides form preferentially at faults in the matrix, and once formed probably anchor them. The striations in the needles of tempered martensite could be indications of the slip accompanying the austenite to martensite transformation described by Geisler,[3] and rendered microscopically visible by carbide precipitation. Our observations on the retained austenite do not quite agree with those of Teague and Ross. We observed a fine structure in the retained austenite of the sample tempered at room temperature. We do not know whether this structure is the result of recovery in the austenite as proposed by Lement, Averbach, and Cohen[4] or it was already present in the sample as quenched and was brought out during tempering. This structure, as far as our work indicates, appears stable to the M_s temperature. Our observations, therefore, would lead us to consider changes in the matrix as well as those in the precipitate during tempering of martensite.

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[3] Alfred H. Geisler, "Crystallography of Phase Transformations," *Acta Metallurgica*, Vol. I, May, 1953.

Isothermal Transformation Near the M_s :

Figures 19 and 20 show the same appearances as observed by Teague and Ross for the *isothermal transformation at 350 F*: (1) a fine precipitate, possibly epsilon carbide, in the bainite needles, (2) an appreciable coarsening of the precipitate in some needles, (3) a film of carbide around some of the needles, and (4) an increase in the size of the needles as compared to those found in the martensite tempered at 350 F.

Figure 21 brings out the change in appearance of the carbide particles and disappearance (taking place, but not quite complete in our micrograph) of the carbide films around the bainite needles as the temperature of isothermal transformation is increased to 500 F. In the same micrograph, two types of carbides appear to be present, in agreement with the electron diffraction work of Austin and Schwartz (reference 6 of paper by Teague and Ross).

Our results of partial transformation at 500 F (Fig. 22) agree to a large extent with those of the authors, except that our micrograph differentiates between retained austenite and tempered martensite in the matrix surrounding the bainite needles. A similar difference was already pointed out between Fig. 2 (Teague and Ross) and Fig. 14 of martensite tempered at room temperature. This difference may be due to a slight variation in the degree of tempering of the martensite.

CONCLUSIONS

Our results are essentially in agreement with those of Teague and Ross. We also observed that the epsilon carbide may be present after tempering at temperatures covering a range of several hundred degrees Fahrenheit. The appearance of cementite may be more closely defined and seems to coincide nearly with the M_s temperature.

We believe that recovery of the matrix should be considered, as well as the changes in the carbide composition and morphology.

The degree of reproducibility of the two sets of micrographs obtained by two different laboratories and the consistent changes in the microstructures observed are, we believe, added evidence of the suitability of the electron microscope for studies of this nature.

MESSRS. D. M. TEAGUE AND S. T. ROSS (*authors*).—We should like to thank Pellier and Rowe for the extensive and valuable comments regarding the tempering of martensite and structure of bainite. Their electron micrographs supplement the original observations in a very useful fashion.

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[4] B. S. Lement, B. L. Averbach and Moris Cohen, "Microstructural Changes on Tempering Iron-Carbon Alloys," paper presented meeting Am. Soc. Metals, Cleveland, October, 19–23, 1953.

We are entirely in agreement with the observation that the matrix of tempered martensite exhibits a slightly tetragonal lattice structure, according to diffraction measurements. This is most certainly due to the ferrite being supersaturated with carbon. However, the definition of tempered martensite as consisting of a carbide precipitate in a matrix of ferrite supersaturated with carbon appears more descriptive and specific than referring to the matrix as martensitic. Reservation of the term "martensitic" for the single-phase supersaturated solution of carbon in iron, produced by rapid cooling, is specific.

We have also noted that retained austenite in the low temperature-tempered samples of this series may appear roughened. This roughness is obtained by over-etching to a point where the fine structure of tempered martensite becomes obscured. We believe that this roughening could well characterize the beginning stages of decomposition of retained austenite to supersaturated ferrite plus carbides. However, we do not consider retained austenite to be the matrix material in tempered martensite structures. We regard it as a separate constituent which undergoes a different type of change during the tempering process.

We want to reemphasize the importance of surface preparation in electron metallography. The fine structures produced by low-temperature tempering are rapidly obscured by deep etching. Also, without extreme care being taken, specimen surface temperatures can rise to such an extent during polishing that further tempering occurs at the surfaces to be replicated.

APPENDIX II

DECOMPOSITION OF AUSTENITE AND MARTENSITE*

By A. E. Austin[1] and C. M. Schwartz[1]

Synopsis

The phases formed in decomposition of austenite and martensite in SAE 1087 steel, from room temperature up to 500 F, have been studied by electron diffraction. Isothermal heat treatment produces cementite at 500 F and epsilon at 400 F. Brine-quenched samples aged at below 100 F contain a transition phase, in addition to martensite and retained austenite. This phase exists at 250 F and may be an ordered structure with a unit cell double that of martensite. Tempering at and above 250 F causes the formation of epsilon phase and, above 500 F, transformation to cementite.

The carbide phases, formed by decomposition of austenite and martensite in plain carbon steel of eutectoid composition, have been studied by means of electron diffraction. Previous work (**1**)[2] with this steel had demonstrated that cementite is produced during isothermal transformation or on tempering of quenched samples above 500 F; at 500 F cementite coexists with the transition phase, epsilon, described by Jack (**2**). In the case of martensite tempered at 400 F, only epsilon was found. Transformations at lower temperatures have now been investigated using a series of specimens prepared as an extension of the program of Subcommittee XI on Electron Microstructure of ASTM Committee E-4 on Metallography.

Experimental Work and Results

The steel was essentially a carbon steel of eutectoid composition (**3**). The specimens were nickel-plated and austenitized at 1800 F in a reducing atmosphere, then either isothermally transformed or brine-quenched and tempered. The specimens were surfaced and polished on low-speed wax wheels. Trichloroacetic acid, trifluoroacetic acid, and nitric acid, each in alcohol solution, were used as etchants. The etch depth was comparable to that used in electron microscopy. To avoid subsequent corrosion of the etched surfaces, the specimens were rinsed only with absolute alcohol and, while still wet, were loaded into the electron diffraction camera, which was then immediately evacuated. This procedure was effective, since the etch products were soluble in alcohol and the alcohol film protected the metal surface against atmospheric attack. Table I lists the heat treatments, structures, and identification of the carbide phases from the electron-diffraction

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* Presented at a meeting of Subcommittee XI on Electron Microstructure of ASTM Commitee E-4 on Metallography, Atlantic City, N. J., June 29, 1955.

[1] Battelle Memorial Inst., Columbus, Ohio.

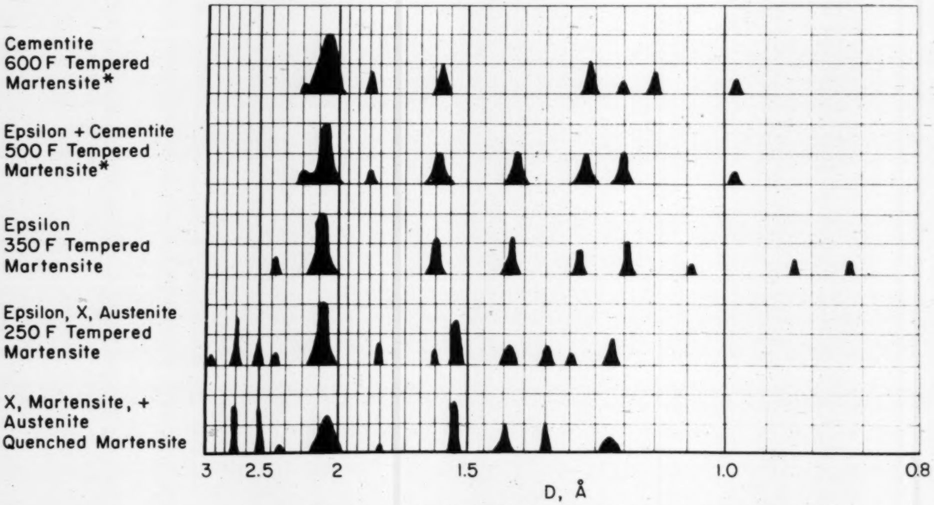
[2] The boldface numbers in parentheses refer to the list of references appended to this paper, see p. 625.

TABLE I.—ELECTRON-DIFFRACTION IDENTIFICATION OF THE PHASES IN STEEL SPECIMENS.

Specimen	Heat Treatment After Austenitizing[a]	Rockwell Hardness, C Scale	Structure	Phases Identified
No. 28	30 min at 450 F and brine quenched	65	450-F bainite, 20 per cent transformed	Epsilon iron carbide and austenite
No. 29	5 hr at 450 F and brine quenched	58	450-F bainite	Epsilon iron carbide, cementite, and austenite
No. 30	12 min at 500 F and brine quenched	64.5	500-F bainite, 5 per cent transformed	Cementite
No. 31	Brine quenched	66	Quenched martensite	X,[b] austenite, and martensite
No. 32	Brine quenched and tempered 1 hr at 250 F	65.5	250-F tempered martensite	X, epsilon iron carbide, and austenite
No. 33	Brine quenched and tempered 1 hr at 350 F	62.5	350-F tempered martensite	Epsilon iron carbide
No. 34	One week at 350 F and brine quenched	60.5	350-F bainite and martensite	Epsilon iron carbide

[a] All samples were austenitized 35 min at 1800 F.

[b] This electron-diffraction pattern is not identifiable with martensite, austenite, or epsilon iron carbide and is denoted by X.



*Patterns of 500 F and 600 F Tempered Martensite were Taken from the Authors' 1952 Paper (1).

FIG. 1.—Graphical Representation of Typical Observed Electron-Diffraction Patterns.

patterns. Figure 1 is a graphical representation of the types of observed electron diffraction patterns.

Partial isothermal transformation at 450 F (specimen No. 28) produced epsilon carbide, while some cementite was also formed upon completion of transformation (specimen No. 29). It is not known whether this cementite was precipitated directly from retained austenite or resulted from subsequent transformation of initial epsilon carbide. At 500 F the initial transformation (specimen No. 30) produced cementite. However, it was previously shown (**1**) that both cementite and epsilon carbide were in the fully transformed specimen. The formation of epsilon carbide in the latter case may be the result of strain induced in austenite because of volume expansion during transformation from austenite to cementite (**2**).

Examination of quenched martensite specimens, aged at room temperature for a minimum of 8 months, disclosed a phase whose electron-diffraction pattern was not identifiable with martensite, austenite, or epsilon carbide. The electron-diffraction data indicated that this phase may be an ordered structure with a unit cell approximately double that of either tetragonal martensite or hexagonal epsilon. The pattern could be indexed on the basis of a tetragonal cell with $c/a = 1.12$, $a_0 = 6.0$ Å, and $c_0 = 6.7$ Å, or for a hexagonal cell with $c/a = 1.60$, $a_0 = 5.4$ Å, and $c_0 = 8.84$ Å. These cells appear quite similar to the ordered tetragonal structure found by Jack (**4**) in the decomposition of nitrogen martensite at 120 C. However, the electron-diffraction pattern was not definitely identifiable with Jack's structure. The coexistence of X phase with epsilon carbide in the 250-F tempered specimen suggests that it should be considered a transition structure in the decomposition of martensite.

REFERENCES

(**1**) A. E. Austin and C. M. Schwartz, "Electron-Diffraction Study of Iron Carbides in Bainite and Tempered Martensite," *Proceedings*, Am. Soc. Testing Mats., Vol. 52, p. 592 (1952).

(**2**) K. H. Jack, "Structural Transformations in the Tempering of High-Carbon Martensitic Steels," *Journal*, Iron and Steel Inst., Vol. 169, p. 26 (1951).

(**3**) "Electron Microstructure of Steel, First Progress Report of Subcommittee XI, ASTM Committee E-4 on Metallography," *Proceedings*, Am. Soc. Testing Mats., Vol. 50, p. 444 (1950).

(**4**) K. H. Jack, "The Occurrence and the Crystal Structure of α''-Iron Nitride," *Proceedings*, Royal Soc., A, Vol. 208, p. 216 (1951).

APPENDIX III

X-RAY DIFFRACTION MEASUREMENT OF PHASE COMPOSITION: SUBCOMMITTEE XI ON PLAIN CARBON STEEL TEMPERED MARTENSITE SERIES*

By W. L. Grube[1] and D. P. Koistinen[1]

In the course of the metallographic examination of the low-temperature tempered martensite plain carbon steel specimens being studied by Subcommittee XI on Electron Microstructure of Metals of ASTM Committee E-4 on Metallography, it was desirable to follow phase composition and structural changes by X-ray diffraction. It is the purpose of this paper to present the results of quantitative measurement of retained austenite in this series of specimens, using the integrated intensity method.[2] The crystallographic condition of the martensite in some of the specimens has also been determined and is reported.

The results of the retained austenite measurements are summarized in Table I. These results are based on integrated intensity measurements on four X-ray diffraction maxima of each specimen—the austenite (220) and (311) peaks and the martensite (200) and (211) peaks. The structures included in this series range from a freshly quenched specimen (stored under refrigeration) to the 400-F tempered structure.

Considering first those specimens tempered at 212 F and above, it can be seen that as the tempering temperature is raised to 400 F there is a corresponding decrease in the amount of retained austenite present, thus indicating that some austenite is decomposed in this tempering range.

It can also be seen that the untempered specimens contain less retained austenite than the slightly tempered specimens. There is no clear-cut explanation for this, but in the case of the freshly prepared specimen stored under refrigeration, there is the possibility that an additional amount of austenite decomposed between the quenching temperature of 60 to 70 F and the storage temperature of 35 F. It should also be pointed out that the freshly quenched specimen was prepared in the Research Laboratories of General Motors Corp. whereas all the others were prepared at the Fundamental Research Laboratory of the U. S. Steel Corp. The possibility therefore exists that the quenching brine used by General Motors Corp. was held at a lower temperature than that used by U. S. Steel, and this factor may account for the smaller amount of austenite retained. For those specimens aged at room temperature, there exists the possibility that some of the austenite, not stabilized by an immediate temper, transformed upon aging.

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* Presented at a meeting of Subcommittee XI on Electron Microstructure of Metals of ASTM Committee E-4 on Metallography, Atlantic City, N. J., June 29, 1955.

[1] Supervisor, Physics of Solids, and Research Physicist, respectively, Research Staff, General Motors Corp., Detroit, Mich.

[2] B. L. Averbach and M. Cohen, "X-Ray Determination of Retained Austenite by Integrated Intensities," *Transactions*, Am. Inst. Mining and Metallurgical Engrs., Vol. 176, pp. 401–415 (1948).

As indicated in Table I, specimen No. 7-3 tempered at 400 F contains less retained austenite near the surface after mechanical polishing than it does after electropolishing, thus indicating that the mechanical polishing decomposes some of the retained austenite. The decrease measured in this specimen (from 10.0 per cent to 8.8 per cent) is comparable to that observed in other plain carbon steel specimens.

Turning to the hardness measurements listed in Table I, it can be seen that this series exhibits the increase in hardness during the early stages of tempering observed by Cohen and his associates[3] in other steels.

Figure 1 shows microphotometer records of the X-ray diffraction patterns of the freshly quenched, quenched-and-aged, and 212-F tempered specimens. It can be seen that only in the freshly quenched specimen is the martensite markedly tetragonal, thus indicating that both aging at room temperature and tempering at 212 F for 1 hr effectively destroy the martensite tetragonality in this steel.

TABLE I.—RETAINED AUSTENITE CONTENT OF SUBCOMMITTEE XI 1087 STEEL SPECIMENS.

Specimen	Treatment After Quenching	Rockwell Hardness, C Scale	Retained Austenite, per cent
No. 31-1	Stored under refrigeration	64	10.6
No. 31-2	Aged at room temperature	66	8.8
No. 31-3	Aged at room temperature	66	10.9
No. 31-A	Tempered 1 hr at 212 F	65.5	13.4
No. 32	Tempered 1 hr at 250 F	65.5	12.4
No. 33	Tempered 1 hr at 350 F	62.5	11.4
No. 7-1	Tempered 1 hr at 400 F	60.1	10.5
No. 7-2	Tempered 1 hr at 400 F	60.1	9.1
No. 7-3A	Tempered 1 hr at 400 F (after mechanical polish)	60.1	8.8
No. 7-3B	Tempered 1 hr at 400 F (after electropolish)	60.1	10.0

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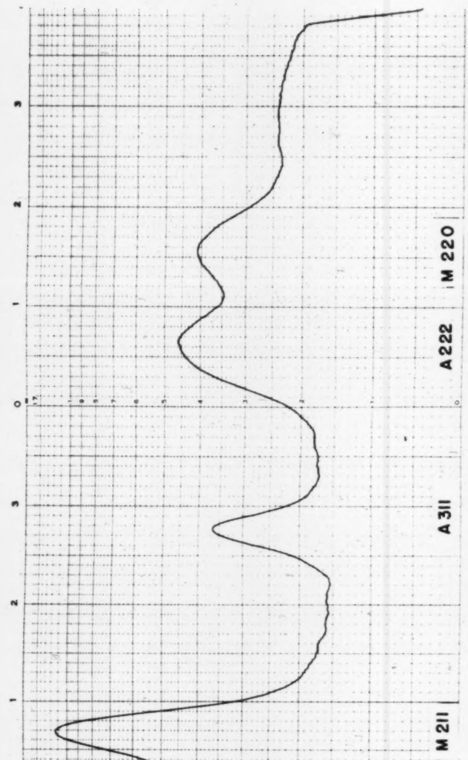
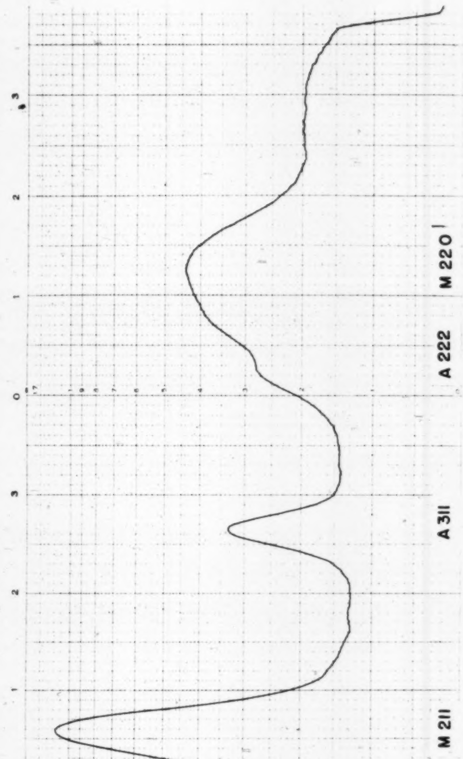
[3] B. S. Lement, B. L. Averbach, and M. Cohen, "Microstructural Changes on Tempering Iron-Carbon Alloys," *Transactions*, Am. Soc. Metals, Vol. 46, p. 851 (1954).


AS QUENCHED
M 200
A 220
M 211
A 311
A 222
M 220


AGED AT ROOM TEMPERATURE
M 200
A 220
M 211
A 311
A 222
M 220

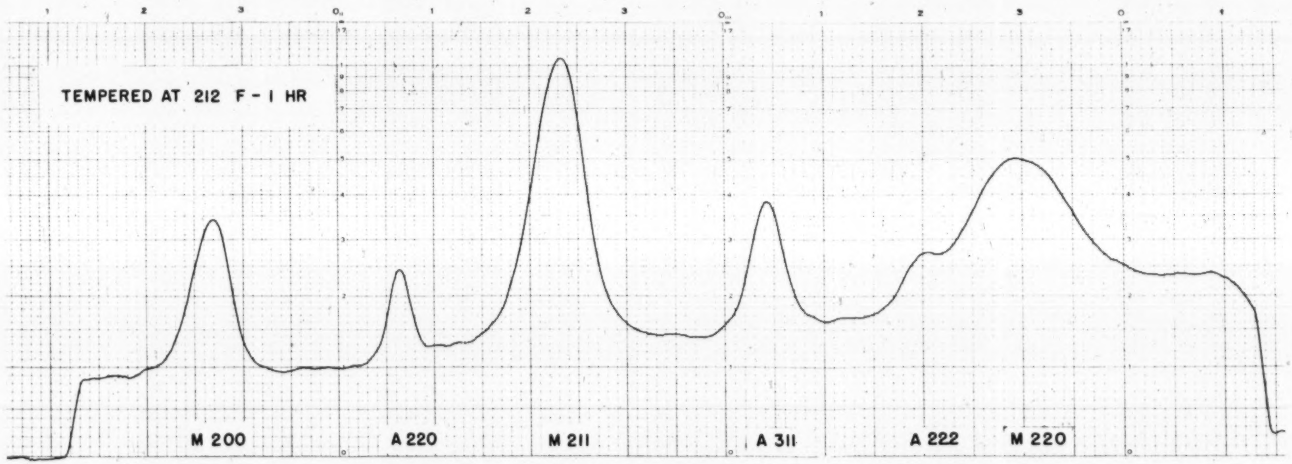


FIG. 1.—X-ray Diffraction Patterns of SAE 1087 Steel Showing Loss of Martensite Tetragonality.

Subcommittee XI specimens austenitized at 1800 F and quenched in brine. Iron Kα radiation, quartz crystal monochromator.

APPENDIX IV

THE SENSITIVITY, REPRODUCIBILITY, AND ACCURACY OF X-RAY DIFFRACTION MEASUREMENTS OF RETAINED AUSTENITE*

By Karl E. Beu[1]

Synopsis

Using an integrated intensity method first proposed by Averbach and Cohen and modified by Beu, retained austenite concentrations have been measured in a series of plain carbon and low-alloy steels over a range of about 1 to 50 per cent austenite without the use of external standards. Various techniques have been used to determine the best sensitivity, reproducibility, and accuracy possible with this method when using iron and chromium Kα radiations.

For best sensitivity, monochromatic radiation is essential for either film or Geiger counter diffraction techniques. Using either iron or chromium monochromatic radiation and film techniques, a sensitivity of 0.2 per cent austenite has been obtained. Using ordinary filtered radiation with either Geiger counter or film technique results in a sensitivity of about 10 per cent; however, a sensitivity of about 1 per cent can be obtained in the special case where chromium radiation and a 0.001-in. thick vanadium metal foil filter is used in front of the argon-filled Geiger counter window. To a first approximation, variation of data, as defined by standard deviation, (*a*) increases with per cent austenite in the sample and (*b*) decreases with the number of diffraction peaks of austenite and martensite included in the calculations.

The accuracy of austenite measurements using monochromatic iron radiation seems to be fairly well established within the limits of reproducibility of the method, since the calculated percentage of austenite is essentially independent of the diffraction peak combinations chosen in the range of 1 to 50 per cent austenite. Furthermore, some correlation work using lineal analysis techniques and special synthetic mixture bulk samples shows excellent agreement with diffraction results. The accuracy of austenite measurements using chromium radiation does not seem to be as good as for iron radiation because of the fewer diffraction peaks that can be used with chromium and the possibility of errors implicit in the chromium *G* factors relating integrated peak intensities and phase concentrations.

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* Presented at the Twelfth Annual Pittsburgh Diffraction Conference, Mellon Inst., Pittsburgh, Pa., November 3–5, 1954, under the title "A Comparison of Film and Geiger Counter Techniques for Measuring Retained Austenite in Hardened Steels."

[1] Supervisor, Physical Measurements Department, Laboratory Division, Goodyear Atomic Corp., Box 628, Portsmouth, Ohio.

An integrated intensity X-ray diffraction technique has been described (**1, 2**)[2] for measuring retained austenite concentrations in hardened steels without the use of external standards or synthetic mixtures. Such a method is essential for these measurements since reliable standards in general are difficult to obtain. Modifications of this technique (**3, 4**) have been developed which render the results less susceptible to bias by the observer and which extend the range of this technique so that absolute percentages of austenite may be calculated using X-ray diffraction data alone on plain carbon or low-alloy steels. Along with developing these modifications, a study has been made of the sensitivity, reproducibility, and accuracy possible using this technique under several different conditions. It is the purpose of this paper to discuss these factors briefly.

SENSITIVITY

Sensitivity depends largely upon the radiation used. Any X-ray wavelength that will cause fluorescence of the sample elements will reduce the sensitivity by increasing background scattering on the diffraction record. Since hardened steels contain iron as a major element and small amounts of manganese and other alloying elements, fluorescence of any of these elements will limit the sensitivity for austenite detection. It is therefore difficult, in general, to use unfiltered, or even ordinary filtered, radiation when maximum sensitivity is desired since some components of the white radiation will cause fluorescence from the sample. Thus, monochromatic radiation is a necessity in this work for maximum sensitivity.

Monochromatic iron Kα is preferable when plain carbon or low-alloy steels are to be examined for retained austenite content. Its principal advantages are: (1) it provides as many as six useful diffraction peaks for measurement, three each of austenite and martensite, and (2) it causes no fluorescence of the iron or manganese which are present in all commercial steels. Monochromatic chromium Kα is a second radiation that is useful for steels containing more than a few per cent chromium or vanadium. These elements fluoresce to iron Kα but not to chromium Kα. On the other hand, chromium radiation has the limitation that only four useful diffraction peaks are available for these measurements.

Figure 1(*a*) is a schematic drawing and Fig. 1(*b*) is a photograph of the X-ray apparatus built for making retained austenite measurements using monochromatic iron Kα radiation. A bent and ground (**5**) quartz monochromator crystal is used to provide a high-intensity, focused, monochromatic X-ray beam at the surface of the sample. The diffraction pattern is recorded on film in from 1 to 4 hr depending on the austenite content; the lower the austenite content, the longer the exposure time required. The sample holder can be used for bulk samples as large as a 2-in. cube, and provisions have been made for rotating a flat sample surface in its own plane to reduce preferred orientation and grain size effects. After processing the film, a microphotometer record is obtained using an instrument particularly adapted for use with X-ray film that minimizes microphotometer noise due to X-ray film grain size (**6**). The percentage of austenite is then calculated from the microphotometer chart using the calculation procedure previously described (**3, 4**).

Geiger counter diffraction data including charts and scaled data were obtained on identical samples using a standard commercial unit for comparison with microphotometer records. It should be emphasized that the Geiger counter data obtained thus far have been only for sensitivity estimations on the standard unit. No austenite calculations have been made using Geiger counter data, nor has the unit been adapted for use with a monochromator crystal.

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[2] The boldface numbers in parentheses refer to the list of references appended to this paper, see p. 643.

Figure 2 shows a comparison of microphotometer records and Geiger counter charts using iron radiation on a group of seven samples ranging in austenite content from 1.1 to 48.7 per cent. The microphotometer records were prepared from two groups of diffraction patterns using (*a*) filtered radiation and (*b*) monochromatic radiation. The Geiger counter charts were prepared using the same filtration in front of the Geiger window as was used for the film patterns.

It can be seen immediately that both the microphotometer records and Geiger counter charts for the same samples are very similar when using nonmonochromatic radiation. No austenite peaks can be detected and measured until the austenite level is up to about 13.4 per cent in either case. It should be pointed out, incidentally, that the microphotometer records and Geiger counter charts are essentially the same whether no filter, one sheet, or as many as eight sheets of manganese dioxide plastic base filter are used. Thus, it seems that both the film and Geiger counter techniques are equally insensitive when using nonmonochromatic radiation. On the other hand, using monochromatic iron Kα radiation, it is possible to detect the A(220) and A(311) peaks,[3] and easily measure 1.1 per cent austenite.

Chromium radiation, on the other hand, has some advantages when using Geiger counter techniques without monochromatic radiation as shown in Fig. 3. If a 0.001-in. thick vanadium metal foil filter is placed in front of the Geiger counter window, it is possible to detect the A(200) peak at the 1.1 per cent[4] austenite level (column *3* in Fig. 3). The use of vanadium foil, however, still does not provide quite as much sensitivity as the monochromatic chromium radiation and film technique (column *2*) where both the A(200) and A(220) peaks can be easily detected and measured at the 1.1 per cent austenite level. Geiger counter scaled data using a vanadium foil filter on these same samples gave nearly identical records as the Geiger counter charts in column *3* of Fig. 3, and for this reason are not illustrated in this figure. The sensitivity of the scaled data and the charts is also approximately the same; that is, the A(200) peak can be detected on either scaled data or charts whereas the A(220) cannot be detected in either case.

It is interesting to compare microphotometer records and Geiger counter charts using two sheets of vanadium pentoxide plastic base filter (columns *1* and *4* of Fig. 3). These records and charts are nearly identical for the same sample, indicating that a given amount of filtration in front of the film or the Geiger counter results in comparable sensitivity. Unfiltered chromium radiation (column *5*) shows no austenite peaks except the A(111) for any concentration of austenite up to about 50 per cent.

The ultimate sensitivity using monochromatic chromium or iron radiation is about 0.2 per cent or about 50 times that for nonmonochromatic radiation. The standard deviation[5] of a set of ten

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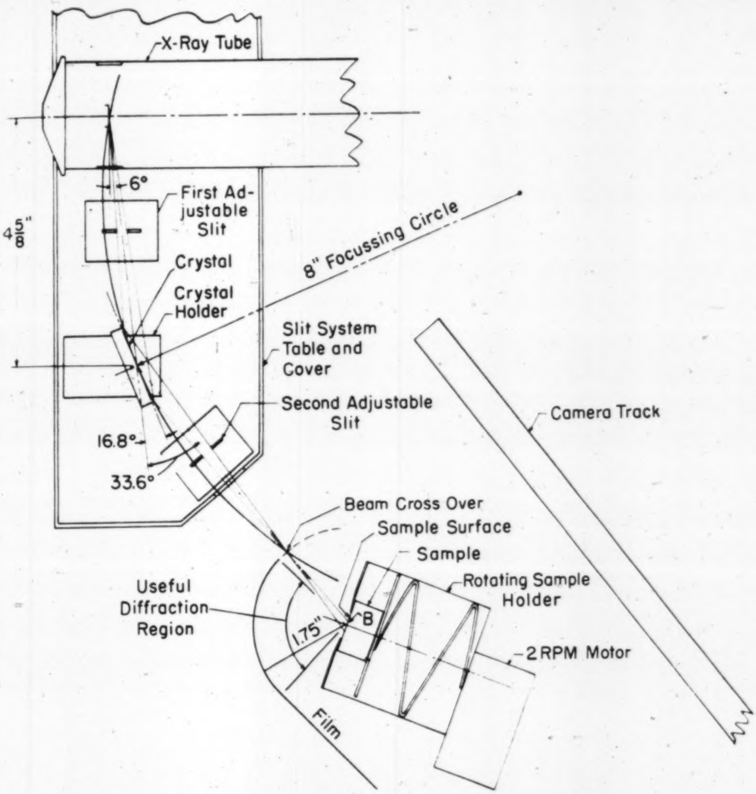
[3] Austenite and martensite diffraction peaks will hereafter be referred to, for example, as A(220) and M(211).

[4] Percentages listed are identical with those of Fig. 2 for comparison purpose only. These percentages were calculated based on iron radiation measurements.

[5] By standard deviation is meant the best estimate of the standard deviation for small groups of samples following a Gaussian distribution according to the equation:

$$\sigma = \sqrt{\Sigma \frac{(x - \bar{x})^2}{N - 1}}$$

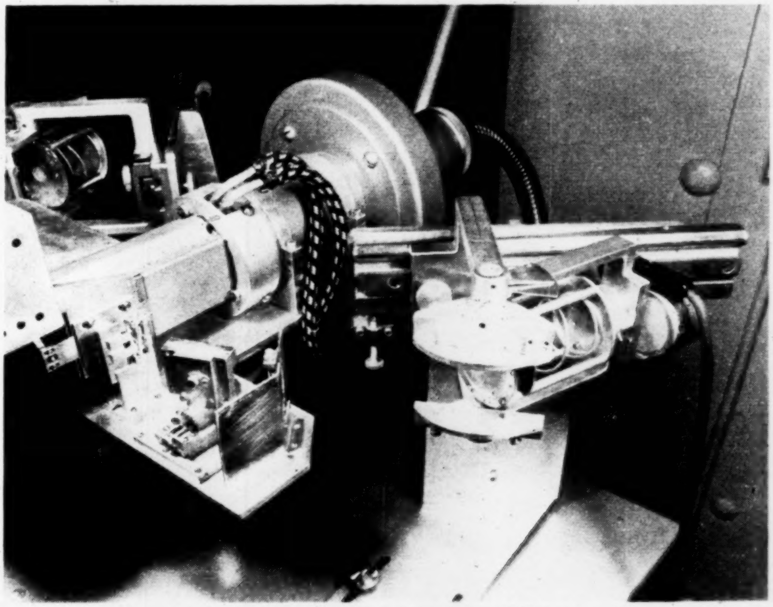

X-Ray Tube
6°
First Adjustable Slit
4 5/8"
8" Focussing Circle
Crystal
Crystal Holder
Slit System Table and Cover
Second Adjustable Slit
Camera Track
16.8°
33.6°
Beam Cross Over
Sample Surface
Sample
Rotating Sample Holder
Useful Diffraction Region
B
1.75"
2 RPM Motor
Film

(*a*) Schematic.

Centerline of main beam at 6 deg to target face. Tangent to crystal face at 16.8 deg to main beam. Centerline of monochromatic beam at 33.6 deg to main beam.

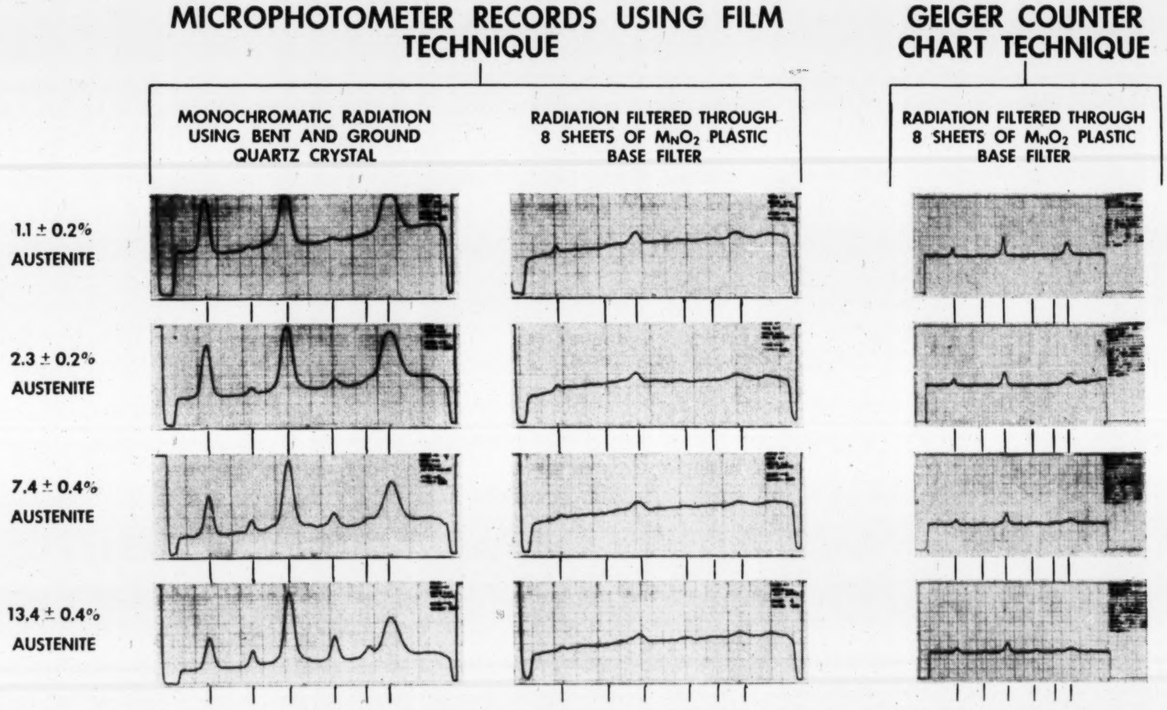
Sample surface can be rotated in its own plane. Angle of sample surface and monochromatic beam adjustable by rotating about vertical axis, *B*. Film holder can also be rotated about *B* so that film can be exposed over desired angular range.

For iron K_α, $\lambda = 1.932$ Å. $(10\bar{1}1)$ planes of quartz have $d = 3.35$ Å.



(*b*) Photograph.

Fig. 1.—Quartz Crystal Monochromator Diffraction Unit.


MICROPHOTOMETER RECORDS USING FILM TECHNIQUE
GEIGER COUNTER CHART TECHNIQUE
MONOCHROMATIC RADIATION USING BENT AND GROUND QUARTZ CRYSTAL
RADIATION FILTERED THROUGH 8 SHEETS OF MnO2 PLASTIC BASE FILTER
RADIATION FILTERED THROUGH 8 SHEETS OF MnO2 PLASTIC BASE FILTER
1.1 ± 0.2% AUSTENITE
2.3 ± 0.2% AUSTENITE
7.4 ± 0.4% AUSTENITE
13.4 ± 0.4% AUSTENITE

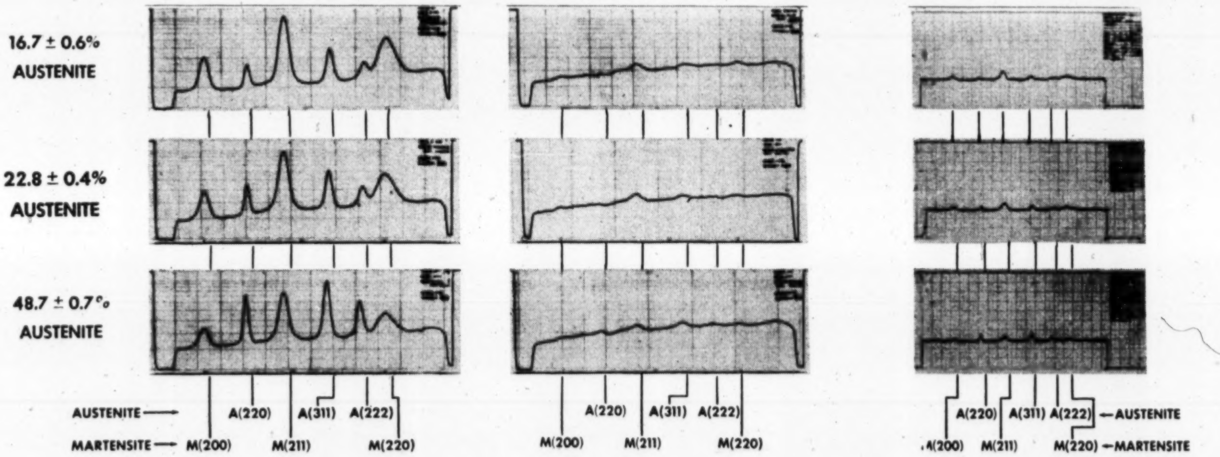


FIG. 2.—Film and Geiger Counter Chart Techniques for Measuring Retained Austenite in Hardened Plain Carbon Steels Using Iron Radiation.

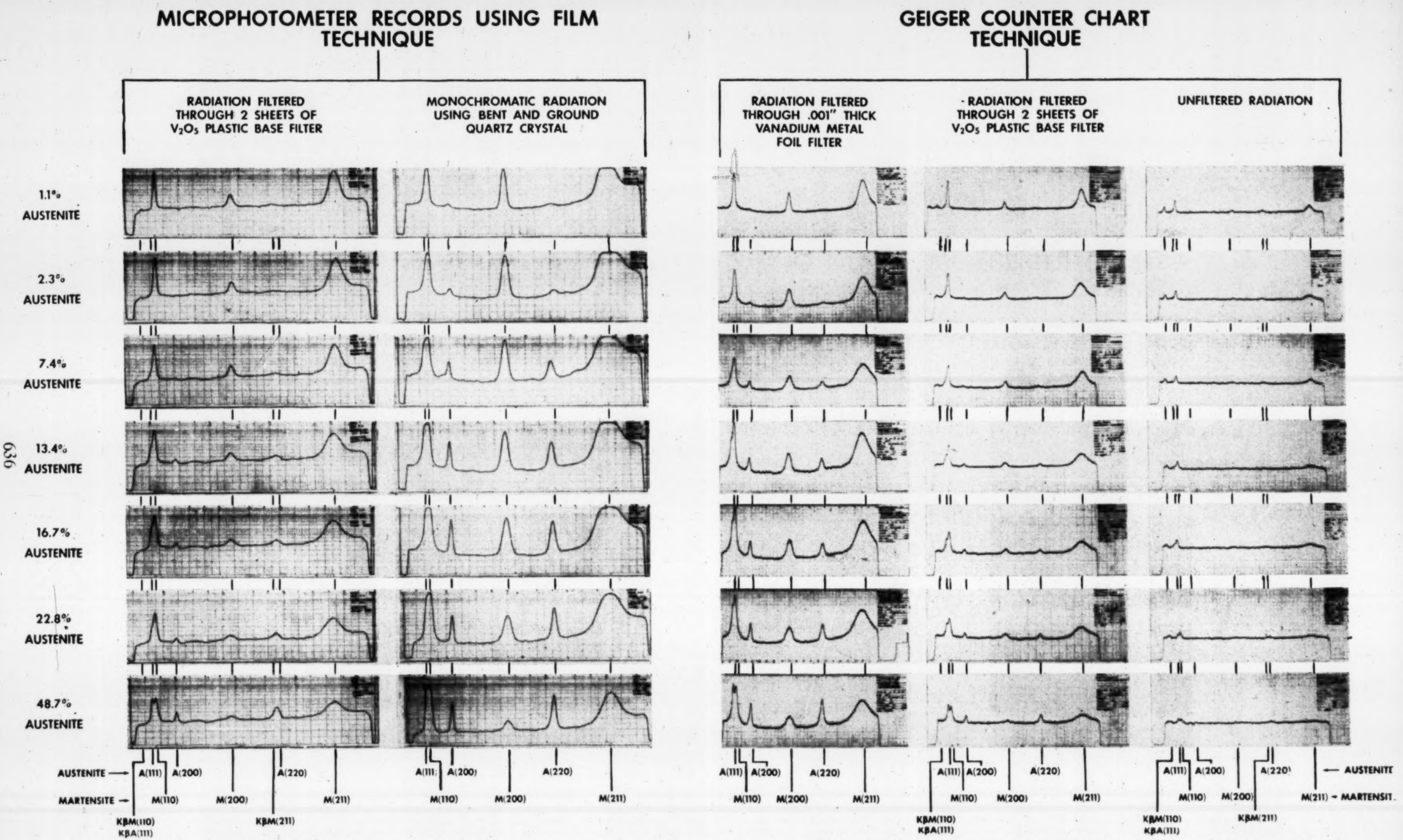


FIG. 3. Film and Geiger Counter Chart Techniques for Measuring Retained Austenite in Hardened Plain Carbon Steels Using Chromium Radiation.

independent measurements on one sample is 0.2 per cent and represents the reproducibility of the monochromatic iron or chromium techniques at the 1 per cent austenite level. Similar reproducibility measurements were made on the other samples in this series, and these results are listed in the left column of Fig. 2. These data are illustrated graphically in Fig. 4 which will now be described.

REPRODUCIBILITY

Standard deviation in terms of percentage of austenite of the total sample is plotted against percentage of austenite in Fig. 4. By extrapolating either of the solid curves to 0 per cent austenite, the absolute value of the standard deviation is found to be about 0.2 per cent, thus indicating that the lower limit of detectability for austenite is about 0.2 per cent.

The curves in Fig. 4 were obtained for three experimental conditions, namely, (1) using monochromatic chromium radiation and two diffraction peaks [the A(220) and M(200) peaks], (2) using monochromatic iron radiation and the same two peaks, and (3) using monochromatic iron radiation and six peaks [the A(220), A(311), A(222), M(200), M(211), and M(220) peaks]. Each point on this graph represents the standard deviation from the average based on ten independent measurements.

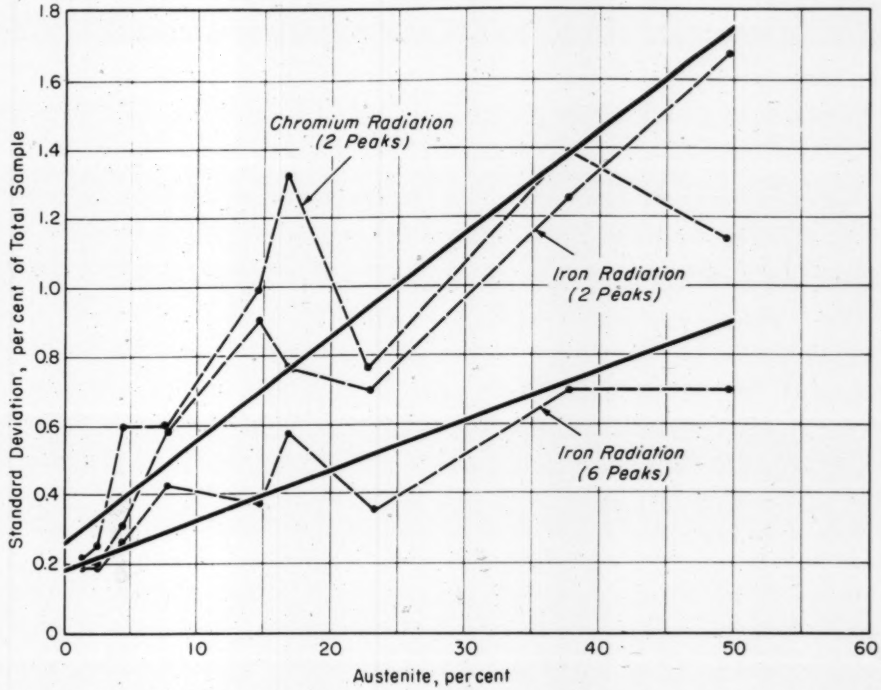


FIG. 4.—Variation in Standard Deviation with Per Cent Austenite for Iron and Chromium Radiation.

From Fig. 4 it can be seen that the standard deviation depends primarily on the number of diffraction peaks measured and not on the particular monochromatic radiation used; that is, the standard deviation using two peaks varies approximately as indicated by the heavy upper curve. When six peaks are used, the standard deviation increases more slowly with austenite percentage as indicated by the heavy lower curve. In addition, the fluctuations in standard deviation with austenite percentage are much less pronounced when using six peaks than when using two peaks. Thus, for best reproducibility it is recommended to use as many diffraction peaks as possible. Since a maximum of six peaks can be used with iron and a maximum of four with chromium, iron is preferred to chromium on this basis.

ACCURACY

An estimate of the accuracy of the integrated intensity method for measuring retained austenite concentrations is difficult to make because of the problem of obtaining standards (**1, 2**). Because reliable standards are not available, in general, two assumptions were made in developing this method. These are: (1) that the sum of the crystalline components in plain carbon or low-alloy hardened steel is equal to 100 per cent of the sample and that the only crystalline components are martensite, ferrite, austenite, and cementite, and (2) that the *G* factors (**3, 4**) relating intensity and concentration are completely evaluated. Except for the presence of intermediate carbides such as epsilon carbide (**7**) which occur at various tempering temperatures, the first assumption is valid. Furthermore, it can be shown that the presence of these intermediate carbides would, in general, have a negligible effect on the absolute value of the austenite determination. Complete evaluation of *G* factors, on the other hand, is not quite as certain. The reasons for this can best be understood by examining the several multipliers of a *G* factor. A *G* factor is defined as follows:

$$G = k \times N^2 \times F^2 \times m \times (\mathrm{L.P.}) \times e^{-2M} \times A(\theta)$$

where:

k = a constant for a given experiment,

N = number of unit cells per cu cm,

F = structure factor per unit cell,

m = multiplicity of reflecting planes,

(L.P.) = Lorentz and polarization factors,

e^{-2M} = Debye-Waller temperature factor, and

$A(\theta)$ = sample absorption factor calculated for a flat sample surface inclined at ϕ deg to the primary monochromatic X-ray beam (**3, 4**).

Of these several explicit multiplying factors, F, (L.P.), e^{-2M}, and $A(\theta)$ are most likely to cause problems when they are evaluated quantitatively. There are at least two reasons for this, namely, (1) the characteristic Debye temperature for iron which occurs in the temperature factor e^{-2M} has been evaluated for iron only (presumably ferrite) (**8**) and not for the other crystalline forms such as austenite and martensite, and (2) all four of the factors just mentioned are sensitive to the angular positions of the diffraction peaks being measured.

The angle-sensitive factors can be evaluated only approximately for the diffraction peaks from a hardened steel because the peak positions vary depending upon (1) the amount of carbon in solution in the austenite, (2) the tetragonality of the martensite and the relative amounts of martensite and ferrite, and (3) the macrostresses introduced into these phases by the heat treatment or surface finishing operations. In addition, the diffraction peaks of austenite and martensite are so broad (several degrees 2θ at half-height) that the determination of a peak position depends on how "peak position" is defined.

In addition to these explicit multipliers in the *G* factors, there are other factors which are implicit and which cannot, in general, be evaluated quantitatively. These implicit factors include, for example, the effects of (1) sample inhomogeneity, (2) primary and secondary extinction, and (3) preferred orientation. That preferred orientation may cause difficulty at all is related to a possible "memory" of the newly formed martensite, ferrite, and austenite grains with respect to the ferrite grain orientation in the soft, cold-rolled bar from which the hardened sample was originally obtained. For reasons such as these, the quantitative evaluation of the explicit and implicit multipliers of the *G* factors for the diffraction peaks in hardened steel is difficult at best.

An experimental method for testing the validity of the *G* factors has been devised. It consists simply of calculating austenite percentages using different combinations of diffraction peaks and X-ray wavelengths. If the calculated austenite percentages agree for a given sample within the limits of reproducibility regardless of the diffraction peak combinations or X-ray wavelengths used, then it is quite likely that the values for the *G* factors are correct. If they do not agree, then there may be discrepancies in either the explicit or the implicit multipliers of the *G* factors which have not been taken into account.

The percentage of austenite has been calculated for the same set of samples illustrated in Figs. 2 and 4 using different combinations of diffraction peaks and X-ray wavelengths. Results on three of these samples are plotted in Fig. 5 for the following peak combinations:

Radiation	Diffraction Peaks Available for Calculation	Number of Peaks Used in Calculation	Number of Peak Combinations Calculated
Iron Kα	A(220), A(311), A(222), M(200), M(211), M(220)	2	6
		3	2
		4	2
		6	1
Chromium Kα	A(200), A(220), M(200), M(211)	2	4
		3	3
		4	1

The vertical shaded areas in Fig. 5 indicate the error in reproducibility to be expected based on calculating pairs of peaks for the austenite level for each of the three samples (see Fig. 4). The width of each band represents a spread of $\pm 1\ \sigma$ (standard deviation) and the band is centered about the austenite percentage calculated by using six diffraction peaks and iron radiation. As can be seen, the spread in calculated percentages for any of the three samples using any combination of peaks is on the order of $\pm 2\ \sigma$. This indicates that there is substantial agreement among the austenite percentages calculated for any combination of peaks using iron radiation. On this basis, it seems that the *G* factors, including the implicit and explicit multipliers, are essentially correct when using iron radiation for these three samples as well as the six other samples studied in this same manner and indicated in Figs. 2 to 4. Since these samples are representative of plain carbon and low-alloy steels, it appears that the *G* factors for iron radiation may be used with some confidence for most plain carbon or low-alloy hardened steels.

The agreement among the austenite percentages calculated for chromium radiation is not quite so good as it is for iron. In Fig. 5, the calculated percentages for pairs of peaks on sample M-199 have a spread of about $\pm 2\ \sigma$ just as they do for the iron percentages on this sample; however, the spread for pairs of peaks for samples M-295 and M-404-1 is greater than $\pm 3\ \sigma$. This spread is probably due to an inadequate evaluation of one or more of the implicit multipliers in the *G* factors rather than in the explicit ones, since the numerical values for the explicit multipliers have the same validity for chromium radiation that they do for iron radiation. Calculated austenite percentages for all nine samples using a maximum number of diffraction peaks are given for iron and chromium radiation in Table I. The exact diffraction peak combinations used for the calculations given in Table I (and Table III) are listed in Table II.

A major limitation of this self-checking X-ray method on the determination of accuracy is that it depends entirely on X-ray measurements. It would be very desirable to have methods independent of X-rays for checking austenite results on identical samples. For this reason some work has been done using the principle of lineal analysis in conjunction with the electron microscope on the same samples as were used for X-ray diffraction measurements. To date, results have been obtained on two samples as follows:

PERCENTAGE OF RETAINED AUSTENITE.

Sample	By Lineal Analysis on Electron Micrographs	By X-ray Diffraction Using Monochromatic Iron Radiation
No. M-463	15.3 ± 6.6	13.8 ± 0.4
No. M-464	18.4 ± 6.0	18.5 ± 0.5

As can be seen, the agreement is well within the experimental error. The X-ray standard deviations were obtained from Fig. 4. The electron microscope measurements were obtained by examining about 15 areas on each sample. Each area was

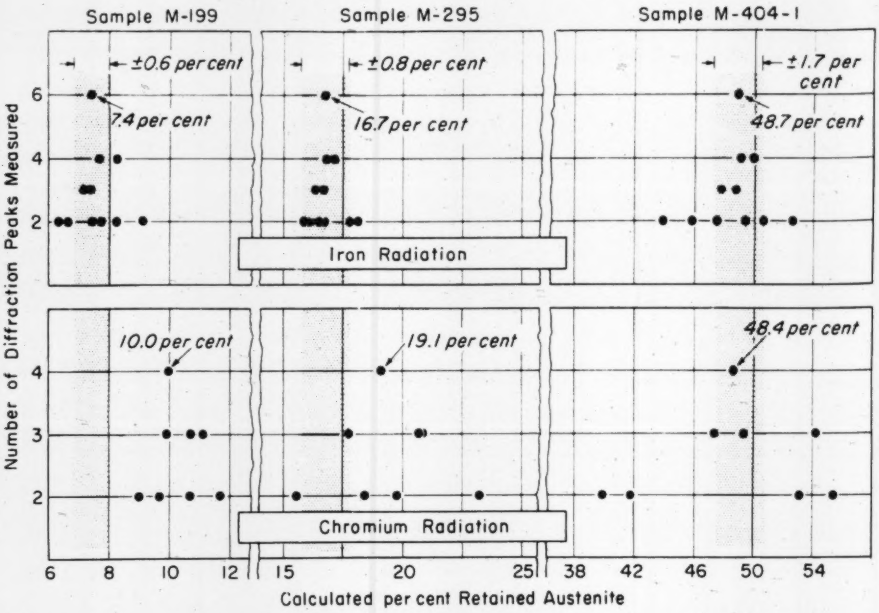


FIG. 5.—Effect of Using Different Diffraction Peak Combinations on Calculated Per Cent Austenite for Iron and Chromium Radiations.

TABLE I.—CALCULATED AUSTENITE PERCENTAGES FOR NINE SAMPLES USING MAXIMUM NUMBER OF DIFFRACTION PEAKS AT EACH AUSTENITE LEVEL.

Sample	Austenite, per cent[a]	
	Using Iron Kα	Using Chromium Kα
No. M-164	1.1 (C)	1.9 (E)
No. M-157	2.3 (C)	3.2 (E)
No. M-168	4.2 (B)	6.3 (E)
No. M-199	7.4 (A)	10.0 (D)
No. M-324	13.4 (A)	16.4 (D)
No. M-295	16.7 (A)	19.1 (D)
No. M-404-2	22.8 (A)	24.1 (D)
No. M-705	37.7 (A)	39.0 (D)
No. M-404-1	48.7 (A)	48.4 (D)

[a] Capital letters after each austenite percentage refer to exact peak combination used. These combinations are given in Table II.

about 10^{-5} sq mm and was enlarged 20,000 to 30,000 diameters for visual examination. The relatively large standard deviations for the microscope measurements can be ascribed to both the small field of view and the relatively small number of the areas examined. The examination of additional areas per sample, however, becomes quite time consuming. The time required, however, can be reduced by using a Hurlbut counter in conjunction with the electron microscope (**9**). When this adaptation is made, additional lineal analyses and X-ray measurements will be carried out on samples covering a wider range of austenite contents.

It was pointed out earlier that standards or synthetic mixtures of austenite and martensite are difficult or impossible to obtain. A primary reason for this limitation is that synthetic mixtures of austenite and martensite cannot be made from the same composition steel. For example, a sample of 100 per cent retained austenite cannot be obtained at room temperature from a hardenable steel although pure austenite can be obtained at room temperature in high alloy steels. On the other hand, pure martensite cannot be obtained at all (**1, 2**). Instead of martensite, pure ferrite that has a body-centered cubic structure very similar to that of martensite may be used as a substitute. In spite of the necessity for making substitutions such as these, it was considered worth while to prepare synthetic mixtures of bulk samples as indicated in Fig. 6.

TABLE II.—DIFFRACTION PEAK COMBINATIONS USED FOR DATA IN TABLES I AND III.

Peak Combination Letter	Characteristic Radiation	Total Number of Peaks Used	Martensite Miller Indices			Austenite Miller Indices				Useful Austenite Range for Calculations, per cent
			(200)	(211)	(220)	(200)	(220)	(311)	(222)	
A..............	Iron	6	x	x	x		x	x	x	Above 5
B..............	Iron	5	x	x	x		x	x		Above 3
C..............	Iron	3	x				x	x		Above 0.2
D..............	Chromium	4	x	x		x	x			Above 10
E..............	Chromium	3	x			x	x			Above 0.2
F..............	Chromium	2	x				x			Above 0.2

Two disks, each of $\frac{7}{8}$-in. diameter, one of pure austenite (12 per cent manganese steel) and the other of pure ferrite (Ferrovac), were cut into matching pie-shaped segments and fitted together. The instantaneous area on the sample exposed to the X-ray beam was about $\frac{3}{8}$ sq in. with the sample being rotated about its center. By rotating the sample at 2 rpm using the special sample holder shown in Fig. 1(*a*) and making exposures of several hours duration, the exposure time will be accurately distributed between the sample segments according to the ratio of angle *R* to 360 deg (see Fig. 6). The percentage of austenite may then

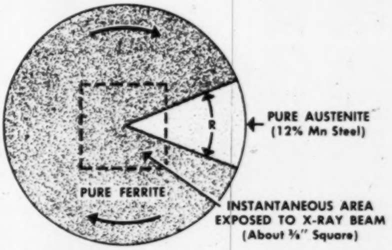

PURE AUSTENITE (12% Mn Steel)
R
PURE FERRITE
INSTANTANEOUS AREA EXPOSED TO X-RAY BEAM (About ⅜" Square)

FIG. 6.—Bulk Synthetic Mixture Sample of Austenite and Ferrite.

be obtained directly from this ratio. A series of five samples in the range of 5.0 to 50 per cent austenite was prepared in this manner, and the results obtained using both monochromatic iron and chromium radiation are given in Table III.

As can be seen, the calculated percentages using iron Kα and as few as three, or as many as six, peaks agree with the percentages based on sample geometry within the reproducibility of measurement for all percentages. This indicates that (1) the accuracy of the integrated intensity X-ray method is adequate even though it was necessary to make sample substitutions, and (2) the response of the X-ray method is linear over a range of at least 45 per cent austenite.

TABLE III.—CALCULATED PERCENTAGE OF AUSTENITE OBTAINED USING SYNTHETIC MIXTURES.

Sample Description		Calculated Percentage of Austenite[a]				
		Iron Kα		Chromium Kα		
Angle *R*, deg	Percentage of Austenite, 100 *R*/360	Using Six Peaks (A)	Using Three Peaks (C)	Using Four Peaks (D)	Using Three Peaks (E)	Using Two Peaks (F)
18.....	5.0	4.9	4.6	...	10.2	10.2
36.....	10.0	11.2	10.7	7.1	14.7	13.6
72.....	20.0	20.5	20.9	16.8	26.1	24.3
108.....	30.0	31.5	32.1	27.7	46.9	42.9
180.....	50.0	50.8	52.6	47.7	59.7	56.1

[a] A, C, D, E, F are peak combination letters (see Table II).

It should be pointed out that the austenite *G* factors had to be modified in making these synthetic mixture calculations because of the manganese in the alloy austenite. These modifications, such as the atomic scattering factor and absorption edge correction, of the *G* factors are given in Table IV which lists our most recent *G* factors both for plain carbon steel and alloy austenite. This table supersedes the one previously published (**3**).

Returning to Table III, the calculated percentages using chromium radiation do not agree among themselves or with the geometrically determined percentages as well as do the percentages obtained using iron radiation. The best agreement with the geometrical percentages is obtained when using four diffraction peaks with chromium. No calculations using four peaks were carried out for the 5 per cent sample because of the great intensity of the M(211) peak compared to the other martensite and austenite peaks. The short exposure required to keep the M(211) peak at a measurable density level on the microphotometer record, that is, a density less than about 1.2, results in the A(200) and A(220) peaks being so underexposed that their integrated intensities cannot be measured with reasonable precision. This same reasoning can be applied, but to a lesser extent, to the 10 per cent sample; hence, the value of 7.1 per cent using four peaks is not too reliable.

TABLE IV.—G FACTORS FOR MARTENSITE, AUSTENITE, AND CEMENTITE.

Crystalline Phase	Iron Kα		Chromium Kα	
	Diffraction Peak	*G* Factor	Diffraction Peak	*G* Factor
Martensite (0% carbon)	(200) (211) (220)	2.27 8.31 6.65	(200) (211)	3.56 24.87
Austenite (0% carbon)	(220) (311) (222)	4.58 10.54 4.41	(200) (220)	3.97 8.22
Austenite (1% carbon)	(220) (311) (222)	4.36 9.52 3.71	(200) (220)	4.94 6.51
Austenite (12% manganese + 1% carbon)	(220) (311) (222)	4.10 8.90 3.46	(200) (220)	4.82 6.34
Cementite (Fe_3C)	(140) (313) (330) (043)	1.44 2.16 1.42	...	...

A reason for including calculations based on three and two peaks per sample when using chromium radiation is to show the marked effect of omitting the M(211) peak in calculating percentages. Calculations based on two peaks, the M(200) and the A(220), are recommended by Littmann (10) since these peaks show the least interference with cementite peaks when undissolved cementite is present in the sample. Even if there is no undissolved cementite present (the synthetic mixture samples contain no cementite), the calculated austenite percentages do not agree too well with the geometrically determined percentages when using chromium radiation. On the whole, the results obtained with these synthetic mixtures both for iron and chromium radiation are compatible with the results given for the nine samples listed in Table I and Fig. 5.

Reviewing the results obtained by the three methods discussed, it seems that the absolute determination of austenite percentages using the integrated intensity X-ray diffraction method and *G* factors is fairly reliable. This seems to be particularly true when using iron radiation and as many as six diffraction peaks. On the other hand, more work is required to clear up the discrepancies between calculated austenite percentages using chromium and iron radiation. This work would involve an extensive survey of the multipliers of the *G* factors, both as to their quantitative value and the significance of the theory behind them. This is beyond the scope of the present investigation.

Acknowledgment:

Thanks are due to Grace M. Huff and Harry W. Sturner who prepared the charts and records and carried out the numerous calculations involved; to Harold L. Schenk for the electron microscope lineal analysis measurements; and to Donald P. Koistinen and Carl E. Bleil who evaluated the *G* factors and estimated their reliability from theoretical considerations. All the above persons have offered many helpful suggestions in the course of this work.

The experimental and theoretical work discussed in this paper was carried out in the Physics Instrumentation Dept., Research Staff, General Motors Corp., Detroit, Mich.

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REPORT OF COMMITTEE E-5

ON

FIRE TESTS OF MATERIALS AND CONSTRUCTIONS*

Committee E-5 on Fire Tests of Materials and Constructions held one meeting during the year: on February 4, 1955, in Cincinnati, Ohio.

The committee consists of 52 members, of whom 23 are classified as producers, 7 as consumers, and 22 as general interest members, with 4 consulting members.

NEW TENTATIVE

The committee recommends for publication as tentative the Methods of Fire Tests of Roof Coverings as appended hereto.[1]

REVISION OF STANDARD AND REVERSION TO TENTATIVE

The committee recommends that the Standard Methods of Fire Tests of Door Assemblies (**E 152 - 41**)[2] be revised as appended hereto[3] and reverted to tentative status.

ADOPTION OF TENTATIVE REVISIONS AS STANDARD

The committee recommends that the tentative revision of Standard Methods of Fire Tests of Building Construction and Materials (**E 119 - 54**)[4] relating to Sections 4, 5, and 6, issued June, 1953, be approved for reference to letter ballot of the Society for adoption as standard.

REVISION OF STANDARD, IMMEDIATE ADOPTION

The committee recommends for immediate adoption the following revision of the Standard Methods of Fire Tests of Building Construction and Materials (**E 119 - 54**)[4] and accordingly asks for the necessary nine-tenths affirmative vote at the Annual Meeting in order that the revision may be referred to letter ballot of the Society.

Section 3(a).—Change the first sentence to read as follows:

> The temperature fixed by the curve shall be deemed to be the average temperature obtained from the readings of not less than nine thermocouples for a floor, roof, wall or partition and not less than eight thermocouples for a structural column symmetrically disposed and distributed to show the temperature near all parts of the sample, the thermocouples being enclosed in sealed porcelain tubes $\frac{3}{4}$ in. in outside diameter and $\frac{1}{8}$ in. in wall thickness, or, as an alternative in the case of base metal thermocouples, enclosed in sealed, standard-weight $\frac{1}{2}$-in. black wrought steel or black wrought iron pipe.

TENTATIVES CONTINUED WITHOUT REVISION

The committee recommends that the Tentative Method of Fire Hazard Classification of Building Materials (**E 84 - 50 T**) be continued as tentative without revision.

The recommendations in this report have been submitted to letter ballot of the committee, the results of which will be reported at the Annual Meeting.[5]

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* Presented at the Fifty-eighth Annual Meeting of the Society, June 26–July 1, 1955.

[1] The new tentative appears in the 1955 Book of ASTM Standards, Part 4.

[2] 1952 Book of ASTM Standards, Part 4.

[3] The revised tentative appears in the 1955 Book of ASTM Standards, Part 4.

[4] 1954 Supplement to Book of ASTM Standards, Part 4.

[5] The letter ballot vote on these recommendations was favorable; the results of the vote are on record at ASTM Headquarters.

ACTIVITIES OF SUBCOMMITTEES

A draft of a fire test method using small size specimens, prepared by a special group at the suggestion of ASTM Committee E-6 on Methods of Testing Building Constructions, is to be considered by the committee in the near future and, if approved, will be published as a proposed small scale test method recommended by the committee without having an ASTM test method designation.

Subcommittee I on Fire Tests of Materials and Constructions (G. N. Thompson, chairman).—The requirements for conditioning of specimens, after having been discussed in the past by the subcommittee with the result that no changes should be made, are again being considered. In addition, possible revision in wording of alternate tests for structural beams and girders and method of determining load failure of load-bearing specimens is under study.

Subcommittee IV on Fire Tests of Acoustical and Similar Finishes (C. H. Yuill, chairman).—The investigation and research at the Forest Products Laboratories on a small tunnel project which has been under way for some time has progressed to the extent that tests on samples identical to those tested in tunnel equipment similar to that outlined in ASTM Tentative Method of Fire Hazard Classification of Building Materials (E 84 – 50 T) should be available some time this year. Correlation of the results of the tests in the two types of tunnels are then contemplated and recommendations will be prepared for submission to the main committee.

Subcommittee V on Nomenclature and Definitions (J. R. Shank, chairman).—A Tentative Method of Test for Use in Defining the Term Non-Combustible As Applied to Building Materials has been prepared and was to be submitted to Committee E-5 members for review. This has not been done due to lack of certain data, but it is now contemplated that the draft will be ready for submission to the committee for review and study prior to the next meeting.

This report has been submitted to letter ballot of the committee, which consists of 52 voting members; 42 members returned their ballots, of whom 41 have voted affirmatively and 0 negatively.

Respectfully submitted on behalf of the committee,

A. L. BROWN,
Chairman.

R. C. CORSON,
Secretary.

REPORT OF COMMITTEE E-6
ON
METHODS OF TESTING BUILDING CONSTRUCTIONS*

Committee E-6 on Methods of Testing Building Constructions held a meeting on June 17, 1954 at Chicago, Ill., during the Annual Meeting of the Society. A special meeting of the Advisory Subcommittee was held at ASTM Headquarters in Philadelphia on February 15, 1955, at which time important policy matters were considered.

The committee consists of 61 members, of whom 52 are voting members. The members are not classified. During the year, 4 individuals have been added to the membership.

The committee regrets to report the death of A. R. Ellis who was a member of the Advisory Subcommittee and Subcommittee 2.

During the 1954 Annual Meeting of the Society in Chicago, the committee sponsored a Symposium on Methods of Testing Building Construction consisting of eight papers. The symposium has since been published as *ASTM Special Technical Publication No. 166.*

ADOPTION OF TENTATIVE AS STANDARD WITHOUT REVISION

The committee recommends that the Tentative Recommended Practice for the Laboratory Measurement of Airborne-Sound Transmission Loss of Building Floors and Walls (**E 90 - 50T**)[1] be approved for reference to letter ballot of the Society for adoption as standard without revision.

REVISION OF STANDARD, IMMEDIATE ADOPTION

The committee recommends for immediate adoption revisions of the Standard Methods of Conducting Strength Tests of Panels for Building Construction (**E 72 - 54**)[1] as appended hereto[2] and accordingly asks for the necessary nine-tenths affirmative vote at the Annual Meeting in order that the revisions may be referred to letter ballot of the Society.

STANDARD CONTINUED WITHOUT REVISION

The committee recommends that the Standard Methods of Testing Truss Assemblies (**E 73 - 52**)[1] be continued without revision.

The recommendations in this report have been submitted to letter ballot of the committee, the results of which will be reported at the Annual Meeting.[3]

This report has been submitted to letter ballot of the committee, which consists of 52 voting members, of whom 39 have voted affirmatively and 0 negatively.

Respectfully submitted on behalf of the committee,

R. F. LEGGET,
Chairman.

R. A. BIGGS,
Secretary.

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* Presented at the Fifty-eighth Annual Meeting of the Society, June 26-July 1, 1955.

[1] 1952 Book of ASTM Standards, Part 4.

[2] The revised standard appears in the 1955 Book of ASTM Standards, Part 4.

[3] The letter ballot vote on these recommendations was favorable; the results of the vote are on record at ASTM Headquarters.

REPORT OF COMMITTEE E-7

ON

NON-DESTRUCTIVE TESTING*

Committee E-7 on Non-Destructive Testing met at Chicago, Ill., on June 16, 1954, in conjunction with the Annual Meeting of the Society, and also on February 3, 1955, during Committee Week in Cincinnati, Ohio. Several subcommittee and Executive Council meetings were held prior to both main committee meetings.

A technical session is planned for Tuesday, June 28, during the 1955 Annual Meeting, in addition to the usual committee meetings. One feature of the technical session will be a round table discussion by representatives of various agencies on the use of ASTM specifications and test methods in the procurement, production, and maintenance of industrial raw materials and products.

The membership of the committee is now 123, plus 20 consulting members.

Recommendations Accepted by the Administrative Committee on Standards

Subsequent to the 1954 Annual Meeting, Committee E-7 presented to the Society through the Administrative Committee on Standards the Tentative Reference Radiographs for Steel Welds. The reference radiographs were accepted by the Administrative Committee on March 23, 1955, and the descriptive text will appear in the 1955 Book of ASTM Standards, Part 1, bearing the designation E 99 - 55 T.[1]

New Tentative

The committee recommends for publication as tentative the Proposed Method for Dry Powder Magnetic Particle Inspection, as appended hereto.[2]

The recommendation in this report has been submitted to letter ballot of the committee, which consists of 123 members; 75 members returned their ballots, of whom 53 have voted affirmatively and 1 negatively.

Activities of Subcommittees

Subcommittee II on Reference Radiographs (Alexander Gobus, chairman).—Work is under way on an expansion of the Tentative Reference Radiographs for Steel Welds (E 99 - 55 T) to include, in addition to the metallic arc welds, other types such as gas welds and submerged arc welds. A task group is working on an expansion of the Industrial Radiographic Standards for Steel Castings (E 71 - 52). The higher penetration of modern radiographic equipment has increased the range of thicknesses readily inspected.

Subcommittee III on Magnetic Particle and Penetrant Inspection (H. Migel, chairman).—The Proposed Tentative Method for Dry Powder Magnetic

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* Presented at the Fifty-eighth Annual Meeting of the Society, June 26–July 1, 1955.

[1] The actual reference radiographs consist of 35 radiographs in the form of transparencies mounted in standard 5 by 8-in. Keysort cards, available for $50 from ASTM Headquarters, 1916 Race St., Philadelphia 3, Pa.

[2] The new tentative appears in the 1955 Book of ASTM Standards, Part 1.

Particle Inspection was developed by this subcommittee. A task group is now collecting a set of standard photographs of magnetic particle indications for discontinuities in steel castings.

Subcommittee V on Radiographic Procedure (C. H. Hastings, chairman) is currently considering specifications for assuring good quality radiographs. A good penetrameter would form the basis for such specifications, but so far there has been no unanimity of opinion.

Subcommittee VI on Ultrasonic Testing (J. C. Smack, chairman).—In final stages are a proposed Tentative Recommended Practice for Ultrasonic Testing by the Reflection Method Using Pulsed Longitudinal Waves Induced by Direct Contact, and a proposed Tentative Recommended Practice for Ultrasonic Testing by the Resonance Method. Also Reference Blocks for Ultrasonic Testing are being considered but will probably not be available until 1956.

This report has been submitted to letter ballot of the committee which consists of 123 members; 78 members have returned their ballots, of whom 71 have voted affirmatively and 0 negatively.

Respectfully submitted on behalf of the committee,

J. H. BLY,
Chairman.

A. GOBUS,
Secretary.

EDITORIAL NOTE

Subsequent to the Annual Meeting, Committee E-7 presented to the Society through the Administrative Committee on Standards the following recommendations:

Tentative Recommended Practice for:

Ultrasonic Testing by the Reflection Method Using Pulsed Longitudinal Waves Induced by Direct Current (E 114 – 55 T), and
Resonance Method of Ultrasonic Testing (E 113 – 55 T).

These recommendations were accepted by the Standards Committee on September 15, 1955, and the new recommended practices appear in the 1955 Book of ASTM Standards, Part 2.

REPORT OF COMMITTEE E-9

ON

FATIGUE*

The pattern of meetings which has been followed has been: Annual Meeting—main committee only; Committee Week—morning meetings of all subcommittees, afternoon meeting of the main committee.

It was evident from the meeting on February 1, 1955, during Committee Week in Cincinnati that there is strong interest in the subject of fatigue; 38 members of the committee attended as well as a considerable number of visitors.

The new members of the main committee consist of W. M. Albrecht, Chain Belt Co., and Bryce Ruley, New Departure Ball Bearing Co., and to the membership of the Aircraft Structural Fatigue Problems Subcommittee have been added H. Tobey, Piasecki Helicopter Corp., J. E. Dougherty, Civil Aeronautics Administration, and J. A. Neilson, Fairchild Aircraft Div. H. F. Moore and J. B. Kommers have been elected Honorary Members.

Translations of the German standards on fatigue have been prepared and have been made available at the Headquarters of the Society.

Subcommittee I on Research (T. J. Dolan, chairman).—Attention has been focused on the fundamental aspects of fatigue. A theory based on dislocations has been brought before the committee.

Subcommittee II on Papers (W. T. Lankford, chairman).—The following papers are being presented at the 1955 Annual Meeting:[1]

"Behavior of Ti-75A Titanium Alloy Under Repeated Load," by R. G. Crum and E. D'Appolonia.

"Strength, Damping, and Elasticity of Materials Under Increasing Reversed Stress with Reference to Accelerated Fatigue Testing," by F. H. Vitovec and B. J. Lazan.

"An Investigation of Strain Aging in Fatigue," by J. C. Levy and G. M. Sinclair.

"Understressing as a Means of Eliminating the Damaging Effect of Fatigue Stressing," by H. E. Frankel and J. A. Bennett.

"The Fatigue Properties of Some Titanium Alloys," by A. W. Demmler, Jr., M. J. Sinnott, and L. Thomassen.

"Torsion Prestrain and the Fatigue Life of RC-55 Titanium Alloy," by J. G. Kaufman and E. D'Appolonia.

"The Fatigue Properties of Wrought Phosphor Bronze Alloys," by G. R. Gohn, J. P. Guerard, and H. S. Freynik.[2]

"Effect of Alloy Content on the Metallographic Changes Accompanying Fatigue," by M. S. Hunter and W. G. Fricke, Jr.

"Axial Stress Fatigue Strengths of Several Structural Aluminum Alloys," by F. M. Howell and J. L. Miller.

"The Effect of Size and Shape of the Specimen, Shape of the Notch, and Grain Size of the Metal on the Fatigue Strength of Smooth and Notched Specimens in Medium Carbon Steel," by Ch. Massonet.

"Anisotropy of Fatigue Strength in Bending and in Torsion of a Steel and Two Aluminum Alloys," by W. N. Findley and P. N. Mathur.

"The Behavior of Long Helical Springs Under Fluctuating Load," by C. L. Staugaitis and H. C. Burnett.

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* Presented at the Fifty-eighth Annual Meeting of the Society, June 26–July 1, 1955.

[1] See Table of Contents of this volume.

[2] Published as part of separate publication *ASTM STP No. 183.*

"The Effect of an Anodic (HAE) Coating on the Fatigue Strength of Magnesium Alloy Specimens," by J. A. Bennett.

For the 1956 West Coast meeting, two sessions on fatigue have been requested.

Subcommittee III on Survey (H. J. Grover, chairman).—During the year the 1953 References on Fatigue (*ASTM STP. No. 9-E*) have been published. The work covering the 1954 References is nearing completion.[3] It is planned to try to add additional abstract information when possible. A survey of current fatigue problems of various laboratories will be undertaken.

Subcommittee IV on Large Machines and Test Correlation (J. M. Lessells, chairman).—It was hoped to have a symposium this year but it is now planned to hold this in 1956.

Subcommittee V on Aircraft Structures (P. Kuhn, chariman).—A report on the status of spectrum loading is being prepared.

This report has been submitted to letter ballot of the committee, which consists of 48 members; 44 members returned their ballots, 44 of whom have voted affirmatively.

Respectfully submitted on behalf of the committee,

R. E. PETERSON,
Chairman.

O. J. HORGER,
Secretary

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[3] Issued as separate publication *ASTM STP No. 9-F*.

REPORT OF COMMITTEE E-11

ON

QUALITY CONTROL OF MATERIALS*

The Tentative Recommended Practice for Probability Sampling of Materials (E 105 - 54 T), prepared by the Task Group on Bulk Sampling, was approved by the Administrative Committee on Standards on September 28, 1954. The aims of this practice are to provide principles for guidance in the preparation of a sampling procedure for a specific material and principles for guidance of other ASTM technical committees. It includes information on the aims of probability sampling, characteristics of probability sampling, minimum standards for a probability sample-design, some problems encountered in the probability sampling of bulk materials, and planning for sampling.

Subcommittee I on ASTM Problems has received the active support of technical committees of the Society. Its membership includes individuals appointed by the technical committees and whose function is to advise Committee E-11 regarding current problems on the application of statistical methods to standardization and to relay back to the technical committees information on the activities of Committee E-11. *Ad hoc* committees on Wool Fiber Measurement and on Sampling of Thermal Insulating Materials have been formed to handle specific requests made to Committee E-11 on problems of general interest involving the application of quality control methods to ASTM standards.

A Task Group on Practical Limits of Uncertainty That May Arise from Sampling, under the chairmanship of J. H. Davidson, has been appointed. Its purpose is to recommend a standard statistical practice for the maximum range of uncertainty that may be attributed to the use of sampling instead of 100 per cent inspection of every item in a lot.

Other active task groups include:

Sampling Plans (O. P. Beckwith, chairman),

Planning Interlaboratory Test Programs (Grant Wernimont, chairman),

Number of Tests for a Desired Precision of an Average (A. G. Scroggie, chairman),

Smoothing Empirical Data (J. H. Curtiss, chairman),

Precision and Accuracy (L. E. Simon, chairman), and

Design of Experiments (W. J. Youden, chairman).

This report has been submitted to letter ballot of the committee, which consists of 19 members; 18 members returned their ballots, all of whom have voted affirmatively.

Respectfully submitted on behalf of the committee,

H. F. Dodge,
Chairman.

O. P. Beckwith,
Secretary.

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* Presented at the Fifty-eighth Annual Meeting of the Society, June 26–July 1, 1955.

REPORT OF COMMITTEE E-12

ON

APPEARANCE*

Committee E-12 on Appearance held two meetings during the year: at Chicago, Ill., on June 15, 1954, and at Roanoke, Va., on February 23, 1955.

ADOPTION OF TENTATIVE AS STANDARD WITH REVISION

The committee recommends that the Tentative Method of Test for 45-deg, 0-deg, Directional Reflectance of Opaque Specimens by Filter Photometry (**E 97 – 53 T**)[1] be approved for reference to letter ballot of the Society for adoption as standard with the following revision:

Section 1.—In the first sentence of Note 1, add the words "ceramic whitewares" after "porcelain enamels."

Section 2.—Add the following new Note 3: "Blue light reflectance by this method differs slightly, both spectrally and geometrically, from the TAPPI methods for paper and pulp brightness."

This recommendation has been submitted to letter ballot of the committee, the results of which will be reported at the Annual Meeting.[2]

ACTIVITIES OF SUBCOMMITTEES

Subcommittee I on Definitions (R. S. Hunter, acting chairman) has revised the proposed Terminology and Geometric Conditions of Measurement for Light Reflectance and Transmittance of Objects and Materials to show more clearly the relationship between geometric attributes of appearance and their scales of measurement. In an effort to secure comments, the revised terminology is being submitted for publication in the ASTM BULLETIN.

Subcommittee II on Color (J. A. van den Akker, chairman) has been gathering data on which to base a general method of color difference measurement and specification. Visual estimates of color difference are being compared with measurements of the same differences with a variety of procedures.

The Symposium on Color of Transparent and Translucent Products, presented by the committee at its Washington meeting. February, 1954, was published in the October and December, 1954, issues of the ASTM BULLETIN and is available as a separate reprint.

Subcommittee III on Gloss and Goniophotometry (H. K. Hammond, chairman) is cooperating with a group in ASTM Committee D-1 on Paint on development of a method of goniophotometry. Interlaboratory comparisons of goniophotometric measurements of a series of ceramic panels are now being run.

This report has been submitted to letter ballot of the committee, which consists of 64 members; 19 members returned their ballots, of whom 18 have voted affirmatively and 0 negatively.

Respectfully submitted on behalf of the committee,

M. REA PAUL,
Chairman.

RICHARD S. HUNTER,
Secretary.

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* Presented at the Fifty-eighth Annual Meeting of the Society, June 26–July 1, 1955.

[1] 1953 Supplement to Book of ASTM Standards, Part 3.

[2] The letter ballot vote on these recommendations was favorable; the results of the vote are on record at ASTM Headquarters.

TECHNICAL PAPERS

With Discussions

GILLETT MEMORIAL LECTURE

THE GILLETT MEMORIAL LECTURE is sponsored jointly by the American Society for Testing Materials and Battelle Memorial Institute in commemoration of Horace W. Gillett, the subjects of the Lectures to pertain to the development, testing, evaluation, and application of metals.

POWDER METALLURGY—NOW (NEW TECHNIQUES, IMPROVED PROPERTIES, WIDER USE)[1]

Fourth Gillett Memorial Lecture

By F. V. Lenel[2]

It is a great honor and privilege to present the fourth annual Gillett Memorial Lecture. This lecture was established jointly by the American Society for Testing Materials and Battelle Memorial Inst. to commemorate the name and achievements of Dr. Horace W. Gillett. I am the first of the Gillett Memorial Lecturers who has not known Dr. Gillett personally. However, through studying some of his books, his papers, and his editorials, reading the tributes of his friends and contemporaries at his passing, and talking to several of those who knew him well, I hope I have been able to gain some insight into Dr. Gillett's personality and his way of thinking. In judging technical writing, Dr. Gillett rightly insisted that the author should present established facts and that fanciful and extravagant claims of the merits of a new process or material should be left to the promoter. Some of the most flagrant violations of this principle of Dr. Gillett's occurred in the early development period of the process about which I am going to speak to you this afternoon, namely, powder metallurgy. Dr. Gillett was not slow to castigate this tendency. In his last book, "The Behavior of Engineering Materials," he gave expression to his feeling that "the early press agenting of the powder metallurgy process was badly overdone" and that "fantastic claims were made whose realization was not accomplished." Having been connected with powder metallurgy for over twenty years, I am well aware how right Dr. Gillett was. It is with a good deal of trepidation, therefore, that I am making this attempt to evaluate some of the developments in powder metallurgy since World War II, the wider use and the improved properties of its products, and the new powder metallurgical techniques that have come to the fore.

Since any lecture on new developments in powder metallurgy must necessarily be selective, it was necessary to chose among the many topics that could be discussed. The choice was made with the thought in mind that this lecture should pertain to the development, testing, evaluation, and application of metals, because this is the field to which Dr. Gillett devoted his life.

My first topic is concerned with the mechanical properties of the so-called "structural parts." Most products of powder metallurgy, such as refractory metals, self-lubricating bearings, cemented carbides, and metallic friction or electrical contact materials, are made from metal powders because they have certain unusual characteristics that cannot be achieved by other fabricating methods. Structural parts, on the other hand, do not have such unusual characteristics. The only reason they are made from powder is that fabrication from powder is more economical than other competing methods. It is therefore easy to see why achieving satisfactory mechanical properties in structural parts is of prime importance.

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[1] Presented at the Fifty-eighth Annual Meeting of the Society, June 28, 1955.

[2] Professor, Metallurgical Engineering, Rensselaer Polytechnic Inst., Troy, N. Y.

In the second part of my lecture, I shall review certain recently developed techniques for making semifabricated products from powder. Some of these new techniques were developed because the extrusions and forgings produced by them have shown properties superior to those of fusion metallurgy. Another new technique for the production of sheet and rod has been introduced as potentially competitive with conventional methods for producing these products.

Finally, I should like to discuss briefly some of the possible uses of the products of powder metallurgy as materials which must have high strength when operating at elevated temperatures. This is a field in the forefront of interest to materials engineers in general. Even though the contributions that powder metallurgy may make in this field lie principally in the future, they should not be left unmentioned.

HIGH-STRENGTH STRUCTURAL PARTS

Structural parts were originally made by techniques borrowed from those of the self-lubricating bearing industry. However, self-lubricating bearings are largely made from bronze, whereas the most important class of structural parts are those made entirely or largely from iron powder. Therefore, the commercial development of structural parts had to await the availability of a suitable iron powder and of industrial furnaces for sintering the parts at the usual sintering temperatures of 2000 to 2100 F. Both these requirements were met in the late 1930's. A type of low-cost powder, the Swedish sponge iron powder of fairly well controlled constant properties, became available. The electric furnace industry developed copper-brazing furnaces in which the parts could be conveyed automatically through a heating zone where they were heated to the necessary high temperatures and into a cooling zone. Both in the heating and the cooling zones, they were protected by a reducing atmosphere. Since parts made from straight iron powder are rather weak and soft, either copper powder was added in amounts from 7 to as much as 25 per cent, or carbon was added in the form of graphite in amounts of 1 to 2 per cent.

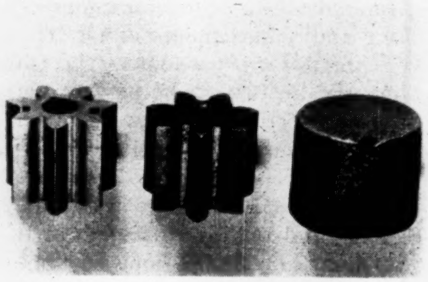

FIG. 1.—Automotive Oil Pump Gears.

From left to right: gear made from powder; machined gear; and cast iron slug from which machined gear was hobbed.

The compacting pressure for iron powder parts was of the order of 30 tons per sq. in. An example of one of the first parts produced in commercial quantities is shown in Fig. 1. This is an oil pump gear for the 1940 Oldsmobile which was made from an iron powder - graphite mixture (**1**)[3] and processed as discussed above. On the left-hand side is the gear made from powder. In the middle is the type of gear which the powder gear replaced and which was machined from the cast iron slug on the right. It is easy to see why this application was a "natural" for powder metallurgy. Hobbing this gear from cast iron is a rather expensive operation in which 64 per cent of the material in the slug is removed as chips. The gear has a uniform cross-section in the direction of pressing so that a comparatively simple set of compacting tools is required, consisting of a diebarrel, an upper and a lower punch, and a core rod (Fig. 2). The dimensional tolerances were such that the surface of the gear teeth did not have to be touched after sintering, and only a small amount of machining on the inside diameter, outside diameter, and length was necessary. The requirements for mechanical properties were moderate, since they were originally met by cast iron. Test specimens of the sintered material, from which the gears were made, had a tensile strength of 20,000 to 25,000 psi with nominal elongation.

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[3] The boldface numbers in parentheses refer to the list of references appended to this paper, see p. 687.

Since these early days, considerable progress has been made in the development of structural parts from powder. Although this is originally an American development, significant contributions have been made by British and continental engineers and metallurgists. We are no longer limited to parts that are uniform in cross-section, as were the oil pump gears; rather complicated designs can now be produced from metal powder, as will be apparent from some of the illustrations in this paper. The development of suitable tooling for these complicated parts is a fascinating subject which I cannot discuss here. My principal topic will be a discussion of the various ways in which the mechanical properties of structural parts made from powder have been improved since the days when the best we could do was to duplicate the properties of a medium-strength grade of cast iron. Before I enter into this discussion, I should like to inject a thought that is perhaps not sufficiently appreciated by the designers of structural parts. Many machine parts are made from steel, either bar-stock or sheet, not because the mechanical properties of the steel are needed but because steel is the cheapest raw material. The question of what strength, ductility, and toughness are actually needed should therefore be considered critically before a high-strength material for a powder part is specified. If a material is specified of higher strength and therefore higher cost than is really required, the expected savings due to fabrication from powders may well become illusory.

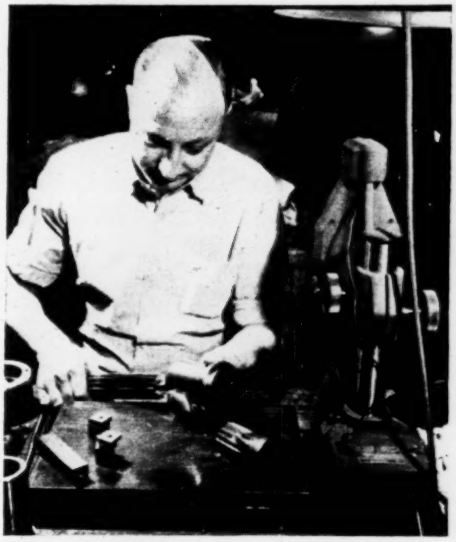
FIG. 2.—Compacting Tools for Automotive Oil Pump Gears.

The quest for improved properties in structural parts started as soon as or possibly even before the commercial production of these parts was under way. It was soon realized that higher strength, and particularly higher ductility and toughness, could be obtained only with increased density. The original oil pump gears had densities of approximately 5.9 g per cu cm, or only 75 per cent of the density of a wrought material of the same chemical composition. There are several ways to achieve higher density. The compacting pressure may be increased. A powder which at a given compacting pressure gives higher density—in other words, a powder of higher compressibility—may be used. The parts after sintering may be subjected to a second pressing operation, usually called "repressing," which results in increased density. In order to make them more ductile, they may also be resintered after repressing. The sintering temperature may be raised to make the parts shrink more during sintering, which will, of course, increase their density. Finally, the pores in the low-density structural part may be infiltrated with a lower melting metal or alloy by capillary action. All of these various methods of increasing the density of ferrous structural parts have their advantages and disadvantages. Instead of discussing them separately, I should like to present a series of examples of structural parts with improved mechanical properties. All of the examples are parts which have been or are being made in quantity commercial production. This should be a good indication that the method by which they are produced is competitive with other more conventional methods of fabrication. In each group of examples, parts made by one particular manufacturer are shown. This does not mean that this manufacturer is the only one who produces that type of parts, but rather that sufficient detail is available for presentation. In spite of this limitation to one manufacturer, I believe the examples will show rather clearly the various directions which the search for improving the mechanical properties of structural parts has taken.

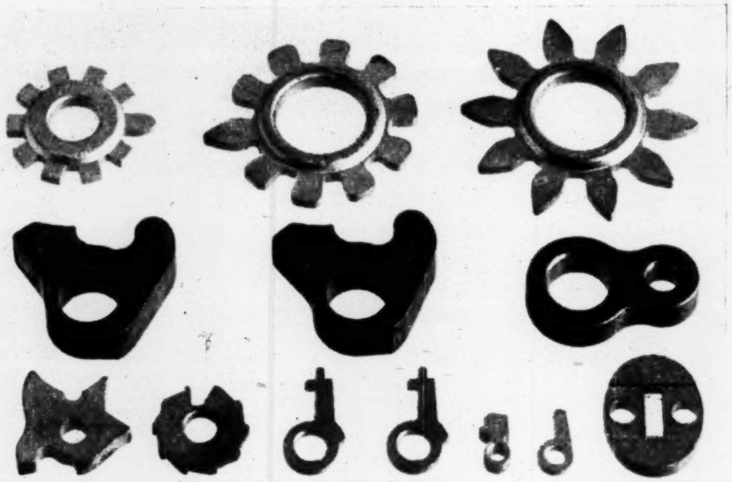

FIG. 3.—Components for Business Machines from Iron Powder Produced by National Cash Register Co.

I shall explain how the parts are made, the advantages and limitations of the fabrication process, some of the difficulties that had to be overcome, and the mechanical properties that were achieved. The mechanical properties were determined not on the parts but on test specimens that had the same density and were produced under the same conditions as the parts themselves. We may safely assume that they are also representative of the properties of the parts. In several of these examples, the improved properties were achieved not only by raising the density but also by adjusting the composition and by adding heat treatments. We should, however, remember that these changes in composition and added heat treatments would have little effect upon low-density structural parts; they influence the mechanical properties significantly only when they are applied to high-density parts.

The parts shown in Fig. 3 are all components of business machines, cash registers, and accounting machines, produced by the National Cash Register Co. All of these components were made from straight electrolytic iron powder, the only addition to the powder mixture being a lubricant, zinc stearate, which volatilized during sintering. The components have densities in the range from 7.3 to 7.7 g per cu cm—in other words up to 98 per cent of the density of SAE 1010 steel from which they were produced before their conversion to powder metallurgy fabrication. The reasons why the company felt that it needed such high-density parts was the requirement of high impact strength, often in conjunction with high wear resistance. Where needed, the parts are made wear-resistant by carburizing and hardening, whether they are made from wrought steel or from powder. Three of the methods for raising density have been used for these parts. They are made from electrolytic iron powder, which has a higher compressibility than most other grades of iron powder; they are compacted at higher pressures; and their fabrication schedule includes repressing and resintering after the first sintering. A typical fabricating schedule (2) and the properties that can be obtained in test specimens (3) which are subjected to such a schedule are shown in Table I. It is obvious that the properties are quite near those of wrought 1010 steel. Such a material can be carburized as readily as wrought steel, whereas it is quite difficult to control the depth of carburization in sintered materials of lower density. Impact tests which duplicate the stresses to which the parts are subjected in actual operation have shown that the parts made from powder are often superior to those made from wrought stock.

TABLE I.—BUSINESS MACHINE PARTS FABRICATED BY NATIONAL CASH REGISTER CO., DAYTON, OHIO.

RAW MATERIAL: Electrolytic iron powder

PROCESSING

Compact at 60 to 65 tons per sq in. to 7.35 to 7.50 g per cu cm density
First sinter 45 to 60 min at 2070 F in endothermic gas to 7.40 to 7.50 g per cu cm density
Repress at 60 to 65 tons per sq in. to 7.65 g per cu cm
Resinter 45 to 60 min at 2070 F

PROPERTIES

Tensile strength	48 000 psi
Yield point	28 000 psi
Elongation	23 per cent

The advantages of this fabrication process are obvious, but there are also limitations. Te begin with, the electrolytic iron powder necessary to obtain high compressibility and high ductility costs as much as three times the lowest priced reduced powders on the market. The parts produced by the National Cash Register Co. are all relatively small, most of them weighing only a fraction of an ounce. The cost of the raw material is therefore a relatively small portion of the total cost of the part. For larger parts, it is quite possible that the relatively high raw material cost would make the powder metallurgy method uneconomical. The high compacting and repressing pressures would cause rapid wear of compacting and repressing tools made of tool steels. These pressures can be maintained only because of the development of tool inserts made of cemented carbides. Proper design of these inserts, particularly for die barrels, has made it possible to produce dies at a cost little higher than that of steel dies despite the higher cost of the carbide (**4**). The carbide dies have also been of great help in overcoming the tendency of metal powder parts to seize in the dies during compacting and particularly during repressing. All of the components in the National Cash Register Co. group are relatively thin, and particularly the ratio of wall area (the area of contact between the powder and the die wall) to the pressing area (the area upon which the punches exert pressure) is small. Only such thin parts can be fabricated to a high density. The procedure of the National Cash Register Co. would not be directly applicable to long slender parts.

Figure 4 shows a group of parts produced in Sweden by Husqvarna Vapenfabriks Co. The three parts on the upper right of the figure are components for a rifle; the four others are sewing machine components. The arm of the sewing machine feeding fork at the bottom of the figure is 6 in. long, which gives an idea of the size of the parts. Husqvarna's fabricating procedure is similar to the one used by the National Cash Register Co. It is outlined in Table II together with the properties which Husqvarna

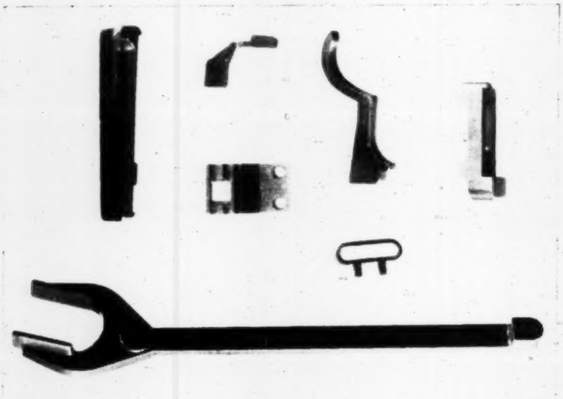

FIG. 4.—Components for Rifles and Sewing Machines from Iron Powder Produced by Husqvarna Vapenfabriks Co.

TABLE II.—COMPONENTS FABRICATED BY HUSQVARNA VAPENFABRIKS, HUSKVARNA, SWEDEN.

RAW MATERIAL:

98 parts electrolytic iron powder
2 parts copper powder

PROCESSING

Compact at 42 tons per sq in. to 6.5 g per cu cm density
First sinter 30 min at 2150 F in hydrogen
Repress at 56 tons per sq in. to 7.2 g per cu cm density
Resinter 1 hr at 2150 F in hydrogen

PROPERTIES

Tensile strength	56 000 to 63 000 psi
Yield strength	50 000 to 53 000 psi
Elongation	12 to 18 per cent
Density	7.2 g per cu cm

reports for test specimens made according to their procedure (5). The tensile strength can be increased to 77,000 to 90,000 psi by age hardening the iron-copper alloy, with a decrease in elongation of 8 to 12 per cent. Still further improved properties are claimed (6) for the material from which the sear is made; this contains 3 per cent copper, 4 per cent nickel, and the balance iron. The properties of this material are reported as 110,000 to 120,000 psi tensile strength with 6 to 8 per cent elongation. Those parts which need high wear resistance, such as the trigger and the sear, are carburized and hardened by Husqvarna by a procedure similar to that followed by the National Cash Register Co. The interesting feature of the Husqvarna process is the addition of alloying elements to the special electrolytic iron powder which Husqvarna produces in its own plant. The copper in this case does not act as a binder or cement for the iron particles, but goes in solution in the iron and exerts a considerable strengthening effect through solid solution or precipitation hardening. In spite of the increased strength, the parts are still adequately tough. The sintered feeding fork, for instance, replaced a steel forging which had to withstand a relatively high impact load.

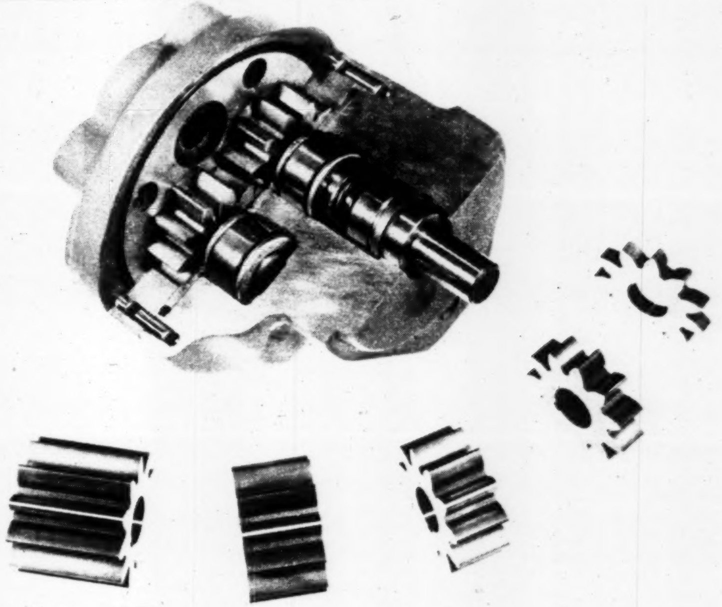

FIG. 5.—High-Pressure Hydraulic Pump Gears from Alloy Steel Powder Produced by Keystone Carbon Co. and Pump Assembly.

I pointed out that high-density iron parts can be made more wear resistant by carburizing and hardening. These treatments will also serve to increase the strength of small parts which can be carburized and hardened to considerable depth. In larger parts, however, only the surface will be hardened because of the shallow hardening characteristics of straight iron-carbon alloys which do not contain even the incidental amounts of manganese and silicon found in plain carbon steels. In order to increase the hardenability, alloying elements must be added. When these additions are made in the form of elemental powders of the alloying elements, it is difficult to obtain complete homogenization at the usual sintering temperatures and times because of their slow rate of diffusion into iron. To overcome this difficulty, alloy steel powders have been put on the market. These powders are produced by atomizing a stream of molten alloy steel (7) and therefore do not depend upon the sintering treatment for homogenization. Gears made by Keystone Carbon Co. from one of these alloy steel powders are shown in Fig. 5, together with the high-pressure hydraulic pump assembly in which they are used. The gears look somewhat similar to the automotive oil pump gears in Fig. 1, but their mechanical properties are very different, as will soon become clear. The gears are compacted from a steel powder having the composition of SAE 4630 with nominally 0.25 per cent molybdenum, 2 per cent nickel, and 0.30 per cent carbon. This analysis is chosen, because any oxides of this alloy steel which may exist on the surface of the powder particles are readily reduced in the usual atmospheres for sintering iron-carbon alloys. The fabricating procedure (8) for these gears consists of compacting in a cemented carbide-lined die, sintering at 2200 F in an atmosphere neutral to the steel with regard to carbon potential, repressing in the compacting die, resintering at 2200 F, and final repressing to a density of 7.5 g per cu cm. After the final repressing, the gears are annealed and heat-treated, a process which includes quenching in oil from 1600 F. The heat-treated gears have a Rockwell C hardness of 30. In spite of the expensive double repressing and resintering, it is reported that the alloy steel powder

TABLE III.—MECHANICAL PROPERTIES OF TEST SPECIMENS FROM 4630 ALLOY POWDER.

PROCESSING

Compact at 40 tons per sq in.
Sinter ½ hr at 2100 F in atmosphere adjusted to carbon content
Repress at 60 tons per sq in.
Resinter at 2100 F
Second repress at 60 tons per sq in.
Second resinter at 2100 F

PROPERTIES

	Tensile Strength, psi	Yield Strength, 0.02 per cent Offset, psi	Elongation, per cent
After second resinter	84 100	66 600	2.8
Quenched from 1600 F			
and tempered 3 hr at 1200 F	96 200	92 500	1.3
and tempered 3 hr at 900 F	129 300	125 300	0.7
and tempered 3 hr at 600 F	149 100	...	0.0
and tempered 3 hr at 300 F	149 600	...	0.0

Density 7.31 g per cu cm

gears are competitive with cut alloy steel gears, whose performance they duplicate.

The mechanical properties of double repressed and resintered test specimens from 4630 alloy powder are shown in Table III, together with the procedure used for obtaining these properties (**9**). It is evident that fairly high strength can be obtained with this procedure. The values for ductility are, however, disappointing when they are compared with those of heat-treated wrought steels of the same composition. The quenched material is completely martensitic, and it is not yet understood why the material, in spite of its relatively high density, has such low elongation.

A rather different approach to the production of alloy steel components from powder has been taken in England by Metal and Plastic Compacts Ltd., one of the Birmingham Small Arms group of companies. Instead of using repressing and resintering in order to increase the density of their parts, they raised the sintering temperature from the usual 2100 F to 2375 F. This causes the green compacts to shrink much more during sintering than they would at lower temperatures. Linear shrinkages of 2 to 3 per cent are reported, whereas the usual shrinkage for iron parts during sintering is only a fraction of 1 per cent. In general, higher shrinkage means more difficult control of dimensional tolerances in sintered components. To obtain these higher sintering temperatures, it is also necessary to sinter in molybdenum resistance furnaces in place of the nickel-chromium alloy resistance furnaces usually used in this country for sintering iron parts.

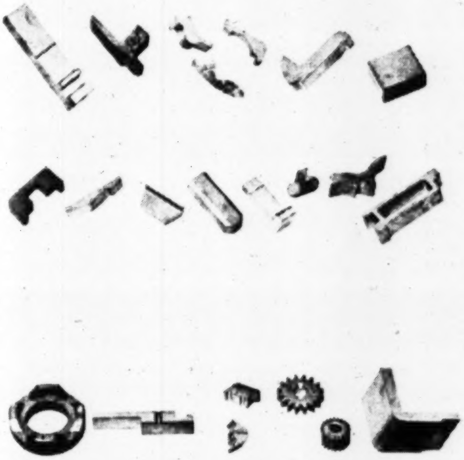

FIG. 6.—Components for Rifles and Miscellaneous Uses from Iron Powder Produced by Metal and Plastic Compacts, Ltd.

On the other hand, these high sintering temperatures apparently permit homogenization of the alloy steel even though the alloying elements, in this case nickel and manganese, are introduced into the powder mixture as elemental carbonyl nickel powder and as manganese carbonate powder. A group of nickel steel components manufactured

TABLE IV.—NICKEL STEEL PARTS FABRICATED BY METAL AND PLASTIC COMPACTS LTD., BIRMINGHAM, ENGLAND.

COMPOSITION	
Swedish sponge iron with 5 per cent nickel	
0.5 per cent manganese	
0.2 per cent graphite	
PROCESSING	
Compact at 40 tons per sq in.	
Sinter 1 hr at 2375 F	
PROPERTIES	
Tensile strength	58 000 to 72 000 psi
Elongation	6 to 12 per cent
Density	7.0 g per cu cm

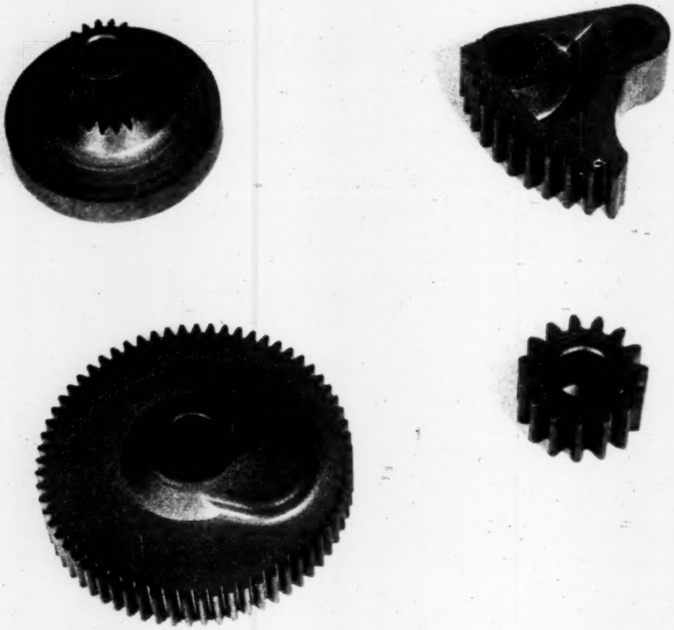

FIG. 7.—Infiltrated Gears for Automatic Clothes Washer from Iron Powder Produced by Moraine Products Division, General Motors Corp.

by Metal and Plastic Compacts in production are shown in Fig. 6. Some of these components are cyanide hardened after sintering. Gun and rifle components are in the first two rows; components for bicycles, dictaphones, textile machines, and miscellaneous uses are in the third row. The composition, processing, and mechanical properties for these British nickel steel parts are shown in Table IV (**10**). It is evident that the relatively high density of these parts, which were made from low-cost Swedish sponge iron at a moderate compacting pressure and without repressing, would be achieved only because of their high shrinkage during sintering. The strength and ductility are of the same order of magnitude as those of the parts made by Husqvarna Vapenfabriks in Sweden.

The last method of increasing the density of porous parts and thereby improving their properties is infiltration with a metal or alloy of a lower melting point than the base metal. The usual infiltrant for iron parts is a copper alloy. Infiltration is, in principle, quite simple, since a porous iron part will readily take up the liquid copper alloy by capillary action when it is brought in contact with it. The details of the infiltration technique must, however, be carefully controlled, since they determine the dimensional changes of the part during infiltration and its surface appearance after infiltration. Since liquid copper dissolves iron, it is often found that at the area where the infiltrant enters the capillary network of the porous part the surface of the part becomes rough or even forms pits. This surface roughening is less pronounced when a copper alloy, which melts over a range of temperature instead of having a sharp melting point like pure copper, is used as the infiltrant. A simple 80–20 brass often is quite satisfactory. Copper-iron or copper-manganese-iron alloys are also used. Several different types of infiltrated materials have been developed, their use depending upon the mechanical properties required in the application. The principal differences in these types concern (1) the composition of the porous part before infiltration, (2) simple pressing and sintering, or pressing, sintering, and repressing before infiltration, (3) use of special techniques to ensure complete infiltration, and (4) heat treatments after infiltration, in particular, precipitation hardening.

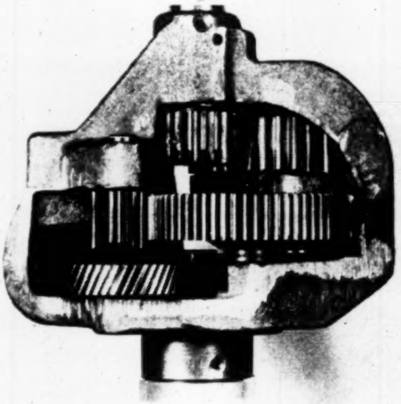

FIG. 8.—Automatic Clothes Washer Transmission with Gears of Fig. 7 Assembled.

I am showing examples of two applications which use different types of infiltrated materials. Figure 7 presents a group of gears produced by Moraine Products Division of General Motors Corp. Together, they form the gear train in the transmission of the General Electric automatic clothes washer. One of the gears, called the dual gear, is compacted with one set of teeth. A second set of helical gear teeth is machined after sintering. The entire transmission with the four gears assembled is shown in Fig. 8. The composition and the processing of the gears and typical properties of the material from which they are made are given in Table V. Of the processing steps, only the powder metallurgical operations, which determine the properties of the material, are included; final machining and finishing operations are omitted. Several of the gears are infiltrated only in those sections where the greatest stresses are applied—for instance, the teeth—and no attempt is made to obtain 100 per

TABLE V.—GEARS FOR GENERAL ELECTRIC AUTOMATIC CLOTHES WASHER.

PROCESSING	
Compact mixture of reduced iron powder and graphite; analysis adjusted to yield 0.8 per cent combined carbon; pressure to give 5.8 g per cu cm density after sintering	
Sinter at 2050 F in exothermic gas scrubbed of water vapor and carbon dioxide	
Infiltrate with 28 per cent by weight of copper alloy at 2050 F	
PROPERTIES	
Tensile strength	84 000 psi
Elongation	$1\frac{1}{2}$ per cent

cent infiltration even in these sections. The mechanical properties apply to the material which is found in the gear teeth. Since the combined carbon content corresponds approximately to a eutectoid composition, the material can be hardened. Use was made of this possibility for one of the gears. The composition and processing of the material for these gears were chosen to give relatively high strength with some sacrifice in ductility. This combination proved most satisfactory for the application.

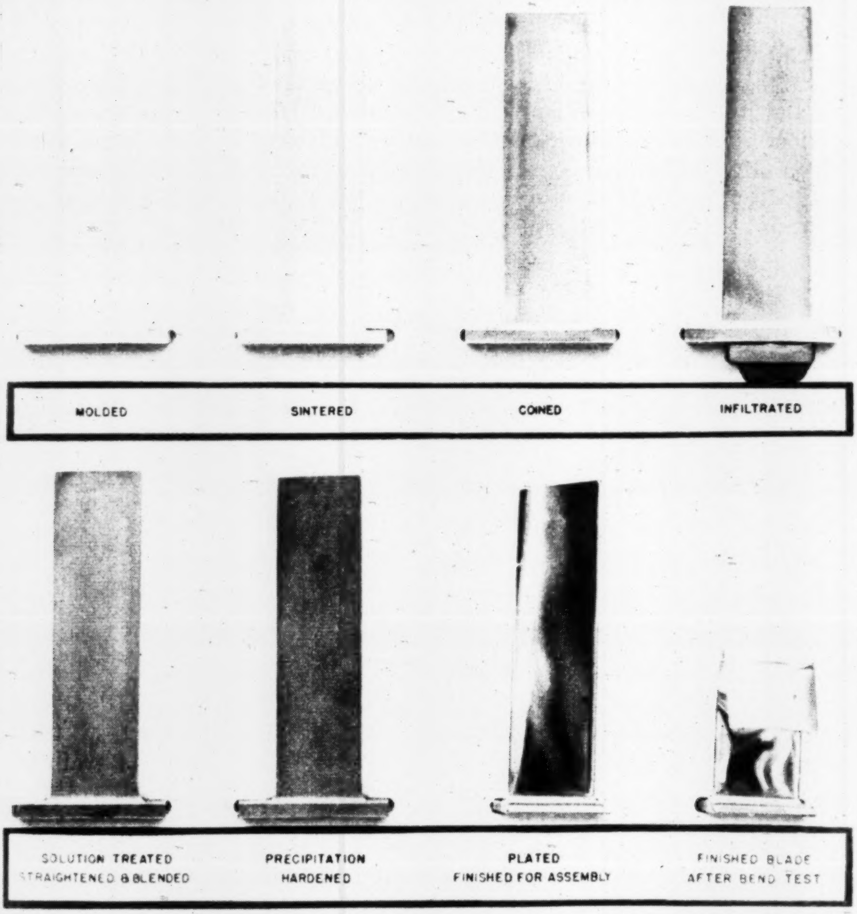
MOLDED
SINTERED
COINED
INFILTRATED
SOLUTION TREATED
STRAIGHTENED & BLENDED
PRECIPITATION
HARDENED
PLATED
FINISHED FOR ASSEMBLY
FINISHED BLADE
AFTER BEND TEST

FIG. 9.—Infiltrated Compressor Blades for Turbojet Engine Produced by Thompson Products.

Infiltrated materials are also used in the blades in Fig. 9, produced by Thompson Products for the compressor of a turbojet engine. They are produced in competition with forged and heat-treated blades from AISI type 403 stainless steel. The processing of the blades (**11**) and the properties of the material (**12**) from which they are produced are shown in Table VI. Again only the initial processing steps are shown; final machining and the finishing chromium plating are omitted. Because of the larger number of operations, this material is, of course, more expensive than the one used for the gears, but it also illustrates clearly what combination of strength and ductility can be achieved in an infiltrated material, where optimum properties are required.

Developing methods for producing ferrous structural parts with improved mechanical properties is a field that is still in flux. I shall therefore not try to draw any final conclusions as to the relative merits of the various methods. How many and which of the methods will eventually survive the competitive struggle will depend at least as much on economic factors as on purely technical ones.

TABLE VI.—COMPRESSOR BLADES PRODUCED BY THOMPSON PRODUCTS.

PROCESSING
Compact mixture of iron and copper powder at 30 tons per sq in.
Sinter 2 hr at 1900 F in dissociated ammonia
Repress
Infiltrate with copper at 2050 F for 4 hr
Repress
Precipitation harden by quenching from 1600 F and aging 45 min at 850 F

PROPERTIES	
Tensile strength	90 000 psi
Yield strength	80 000 psi
Elongation	8 per cent
Hardness, Rockwell B	90

ALUMINUM POWDER METALLURGY

The most interesting among the semifabricated products from powder having properties superior to those of fusion metallurgy are those made from aluminum powder. Aluminum powder particles have an oxide skin which cannot be reduced and therefore appears in the products made from the powder. This oxide was generally considered an unavoidable nuisance in the products of aluminum powder metallurgy. It was therefore quite a surprise when work at the laboratories of the Swiss Aluminium Industrie A.-G. in Neuhausen proved that excellent use can be made of this oxide to improve the mechanical properties of aluminum powder metallurgy products (**13**). This development is being exploited commercially not only in Europe by the Swiss company and their licensees but also in this country by the Aluminum Company of America (**14**). The trade name of the Swiss products is SAP for sintered aluminum powder; the Aluminum Company calls its material APMP for aluminum powder metallurgy product. There are two principal differences between the earlier approach of producing structural parts from aluminum powder and the new developments. In the first place, most of the powders that are used are flake powders which, at least in one direction—the flake thickness—are much finer than the usual atomized aluminum powders. The flake thickness of these powders is between 2 and 0.2 μ, whereas even the finest atomized powders have particle diameter of about 3 μ. Concurrent with the thinness of the flakes is their increased oxide content, which for the thinnest flakes may reach 15 and 20 per cent by weight of oxide.

The second difference is in the technique of fabricating the new products. Instead of cold pressing the powder and subsequently sintering the compacts without the application of pressure, the new products are hot pressed, which means that compacting and sintering are done simultaneously. The hot pressed compacts are then further hot worked, by hot extrusion or hot forging. It is evident that the new products are not "structural parts" in the usual meaning of this word in powder metallurgy jargon. In other words, the purpose is not to pro-

TABLE VII.—ROOM-TEMPERATURE TENSILE PROPERTIES OF COMMERCIAL ALUMINUM POWDER EXTRUSIONS.

Grade	Oxide Content, per cent	Tensile Strength, psi	Yield Strength, 0.2 per cent Offset, psi	Elongation, per cent
SAP 865....	Approx. 11	48 000	35 000	7
M255......	0.5	22 600	17 600	22
M257.......	7.8	39 000	25 000	15
M276.......	16.5	54 000	37 000	5

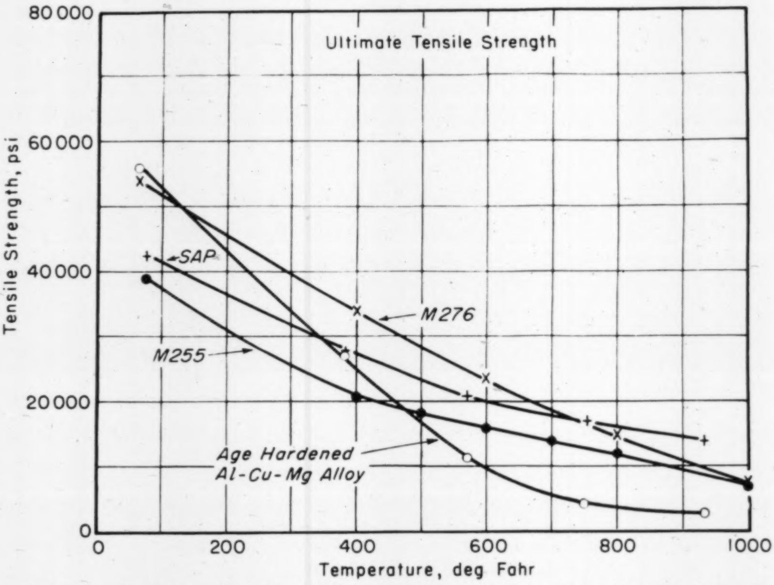

FIG. 10.—Tensile Strength at Elevated Temperatures of Aluminum Powder Extrusions.

duce parts to closely controlled finished dimensions by compacting and sintering but to produce semifabricated products such as extrusions and forgings which have mechanical properties superior to those of conventionally produced semifabricated products, such as extrusions made from cast billets.

To give a picture of these products, I should like to discuss briefly the steps in their fabrication, present some figures illustrating the properties of the products and possible applications for them, and finally tell something about the work that has been done at Rensselaer Polytechnic Inst. in an effort to learn the reasons for the improved properties of these products. The fabrication process has been described by the Swiss investigators (**13**), whose account I am following. The first step is the production of powders suitable for compacting. Aluminum flake powders are important commercial products used as pigments for paints, printing inks, and allied products. These flake powders are made either by stamping of scrap aluminum or aluminum foil or by ball-milling atomized aluminum as a slurry in an organic solvent in a process developed by Hall (**15**). During both stamping and ball-milling, fatty acids are added to the powders to prevent the welding together of the particles and to give desirable properties to the powders for use as pigments. These flake powders for use as pigments have a very low apparent density of 0.1 to 0.2 g per cu cm and are very difficult to compact. Aluminium Industrie A.-G. developed a patented process (**16**) to modify the flaking so that denser flake powders of an apparent density of 0.8 g per cu cm with a minimum amount of fatty acid are produced. The flake powder is next cold-pressed at a pressure of 30,000 to 70,000 psi into compacts having a density of 2.0 g per cu cm. The compacts are hot-pressed at a temperature of 950 to 1100 F and a pressure of 70,000 psi, a procedure that raises their density to practically that of cast aluminum, 2.7 g per cu cm; finally they are extruded or hot forged in the same temperature range and at similar or even higher pressures.

Although Aluminium Industrie A.-G. has produced a number of grades of SAP, at least experimentally, most of the published data on this material refer to one grade, SAP 865, which has an oxide content in the neighborhood of 11 per cent. This is the grade whose properties are shown in the following tables and figures. There are three principal grades of aluminum powder metallurgy products produced by the Aluminum Company of America, whose properties have been published (**14**). The room-temperature tensile properties and the oxide content of the one Swiss and the three American grades are given in Table VII. Grade M255 is produced from atomized powder, the other grades from flake powder. The metallic impurities in all four grades are of the same order as 2S aluminum. Although even grade M255, which is quite low in oxide, is considerably stronger than annealed wrought 2S, the grades higher in oxide have room-temperature, tensile yield strength, and ultimate strength of the order of some of the stronger aluminum alloys. Much more remarkable, however, are the elevated temperature properties of these materials which are shown in Figs. 10 and 11 compiled from both

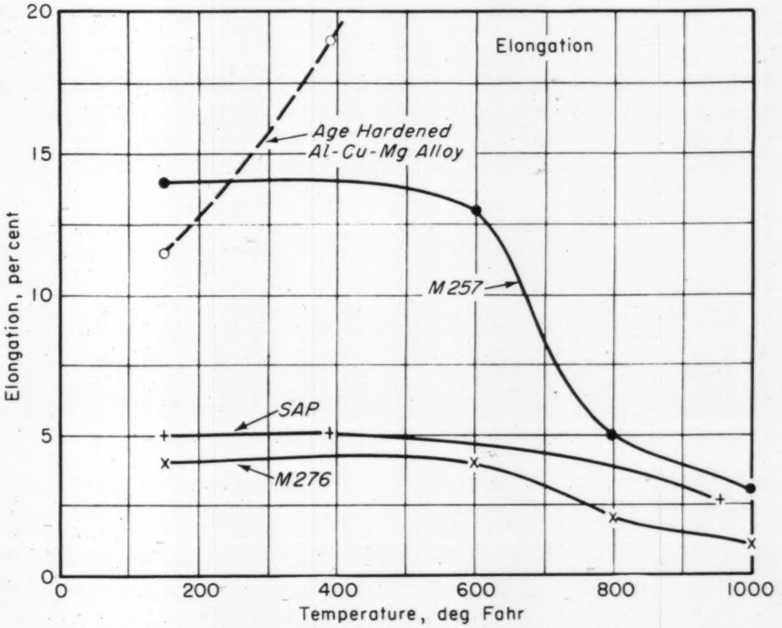

FIG. 11.—Elongations at Elevated Temperatures of Aluminum Powder Extrusions.

TABLE VIII.—STRESS FOR SECONDARY CREEP RATES OF 0.001 AND 0.1 PER CENT PER HR AT 600 AND 800 F.

Grade	Temperature, deg Fahr	Stress, psi	
		Creep Rate, 0.001 per cent per hr	Creep Rate, 0.1 per cent per hr
XF 18S-T61	600	...	6 000
M255	600	3 500	6 000
M257	600	10 000	13 000
SAP	600	14 900	17 400
M257	900	6 100	7 600
SAP	900	8 000	9 400

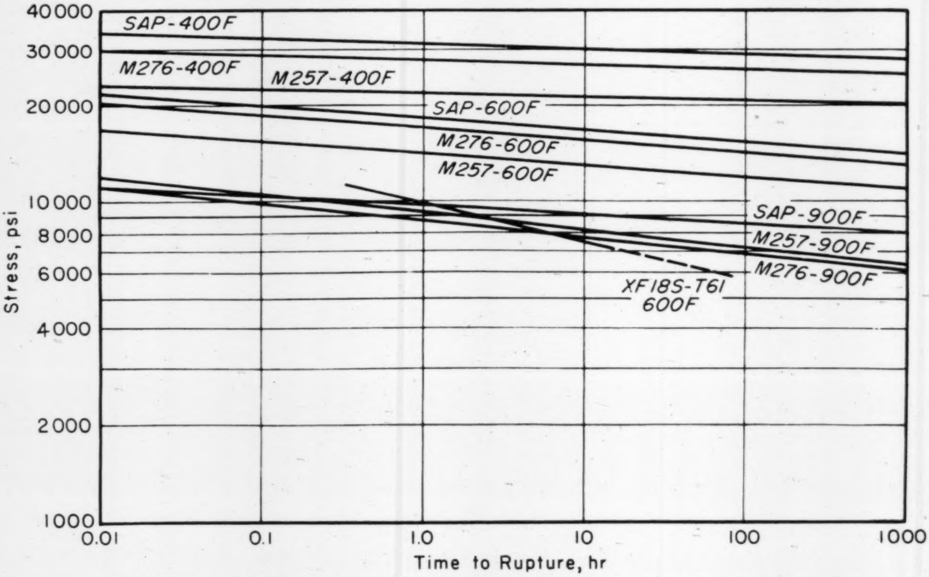

FIG. 12.—Stress to Rupture at 400, 600, and 900 F of Aluminum Powder Extrusions.

Swiss (**13**) and American (**14**) sources. In Fig. 10 the tensile strength of the powder materials are compared with that of one of the wrought age-hardened aluminum-copper-magnesium alloys. At temperatures above 450 F, this alloy rapidly loses its strength because of overaging, whereas the powder metallurgy materials maintain considerable strength even at temperatures as high as 800 F. On the other hand, their ductility, shown in Fig. 11, does not increase but rather decreases with increasing temperature. The materials have another very important characteristic: long-time soaking at high temperatures, as much as a year at 900 F, does not alter their room-temperature properties, but precipitation-hardened alloys lose their strength rapidly above their aging temperature.

The creep and stress-rupture properties of the materials have been investigated by Gregory and Grant (**17**). Values of stress for various secondary creep rates are shown in Table VIII. The superiority of both M257 and SAP with regard to creep rates at 600 F is quite evident; for creep rates of 0.1 per cent per hr, the corresponding stresses for M257 and SAP are two and three times those of an age-hardening aluminum alloy of outstanding strength, SF 18S-T61. Data for stress to rupture at 400, 600, and 900 F are shown in Fig. 12. The fact that the slopes of the curves for M257, M276, and SAP are relatively flat and do not contain any breaks testifies to the

TABLE IX.—FATIGUE BEHAVIOR OF UNNOTCHED AND NOTCHED M257 AND M276 SPECIMENS.

Grade	Temperature, deg Fahr	Fatigue Limits at 10^8 Cycles, psi		Fatigue Notch Factor[a]
		Unnotched	Notched[a]	
M257	800	5000	1800	2.8
	900	3600	1600	2.2
	1000	2700	1200	2.2
M276	800	7700	2500	3.1
	900	6800	2300	3.0
	1000	4200	1600	2.6

[a] Notch has stress concentration factor of 3

Data for the high-temperature fatigue strength of powder alloys M257 and M276 have recently been determined at Battelle Memorial Inst. (**18**) and are summarized in Table IX. Experiments were also made on samples of SAP which indicated that for unnotched samples SAP has a fatigue strength approximately equivalent to M276 at 800 F, but somewhat inferior to M276 at 1000 F. The conclusion drawn by the Battelle investigators is that for unnotched specimens M257 and M276 have fatigue limits at 800 F equal to or greater than many wrought aluminum alloys at 400 to 500 F but that the detrimental influence of notches on the fatigue behavior may be a deterrent to their use.

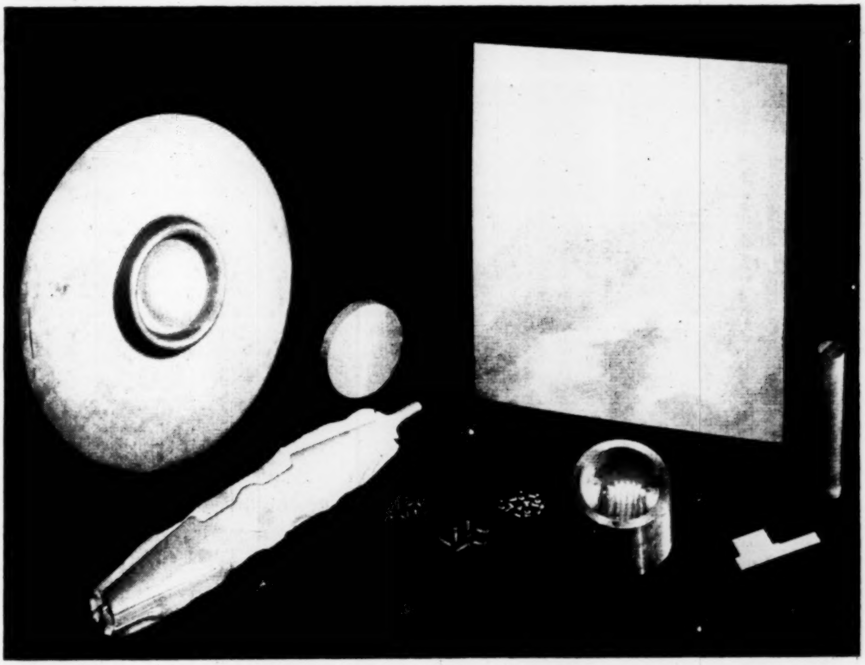

FIG. 13.—Grade M257 Aluminum Powder Metallurgy Products Produced by Aluminum Company of America.

structural stability of these materials. A comparison with the curve for stress rupture of SF 18S-T61 again indicates that not only the short-time but also the long-time high-temperature strength of the powder products is superior to that of conventional wrought alloys.

Summarizing the results of the mechanical tests, it may be said that there can be no doubt that the materials made from powder have unusual high-strength properties both in short- and long-time tests. On the other hand, their limitations, such as relatively low ductility and notch sensitivity, must be taken into account when applications for these materials are considered.

Some of the potential applications of aluminum powder metallurgy products are shown in Fig. 13. All of the products are made from Alcoa's intermediate grade, M257. The large disk is a forged compressor disk measuring 21 in. in diameter and weighing 33 lb. Below it is a forged fan blade that has not been trimmed. Also shown is a forged and rough-machined aircraft piston, and next to it is a 24 by 18-in. sheet. The long cylindrical piece is an impact extrusion. Below it is a slice from an extruded shape. The small pieces between the fan blade and piston are screws, bolts, and rivets. The examples clearly illustrate what can be done with aluminum powder metallurgy, since they were all made on production equipment. It should be remembered, however, that the fabrication of aluminum powder metallurgy products is still in the experimental stage.

One of the most intriguing questions with regard to these new materials is the origin of their unusual properties. To explore this question, a group of extrusions from commercial aluminum flake powders were produced at Rensselaer Polytechnic Inst., in connection with a program sponsored by the Aeronautical Research Laboratory of the Wright Air Development Center. The powder used had been produced for pigment use, which, as pointed out before, is not very suitable for compacting. With an appropriate treatment for removal of fatty acid, they can, however, be pressed and they have the advantage that before the fatty acid removal treatment one very significant property of the powders—namely, their flake thickness—can be readily determined by the so-called covering capacity test. In this test, a weighed sample of powder is spread upon a water surface and manipulated in such a way that an uninterrupted surface of flake powder, just one flake thick, is formed. From the weight of the sample, the surface area occupied, and the density of aluminum, the average thickness of the flakes can be readily calculated. The flake thickness determines the dis-

TABLE X.—OXIDE CONTENT OF FLAKE ALUMINUM POWDERS WITH VARIOUS TREATMENTS.

Supplier	Grade	Average Flake Thickness, μ	Treatments	Oxide Content, per cent by weight
Reynolds Metals Co.	F40	2.3	In vacuum	1.6
Metals Disintegrating Co.	MD2100	0.8	In vacuum	2.8
			2 hr in air	4.7
			113 hr in air	8.5
			In 90-psi steam	10.5
	MD5100	0.4	In vacuum	6.2
	MD3100	0.4	In vacuum	9.7
			17 hr in air	12.0
			In steam	13.5
	MD7100	0.17	In vacuum	13.2
			In air	15.4

tance by which the oxide skins on either side of the flake are separated. It is felt that it is also a relative measure of the distribution of oxide in the powder product, even though during the compacting, hot-pressing, and extrusion of the powder the oxide skins on the flakes are not preserved as such but are broken into small fragments. If the thickness of the flake powder particles is accepted as a measure of the oxide distribution, it becomes possible to distinguish between the influence upon the properties of the extrusions of oxide distribution on the one hand and oxide content on the other.

Extrusions were produced, following closely the Swiss technique outlined above, from five grades of aluminum flake powder, whose properties are shown in Table X. The flake thickness varies from 0.17 μ for the MD7100 powder to 2.3 μ for the F40 powder. The as-received oxide content of the flake powders is higher the thinner the flakes, with the exception of powders MD3100 and MD5100 which had the same thickness but different oxide contents. Through appropriate treatment in either air or steam at elevated temperatures, the oxide content can be artificially raised.

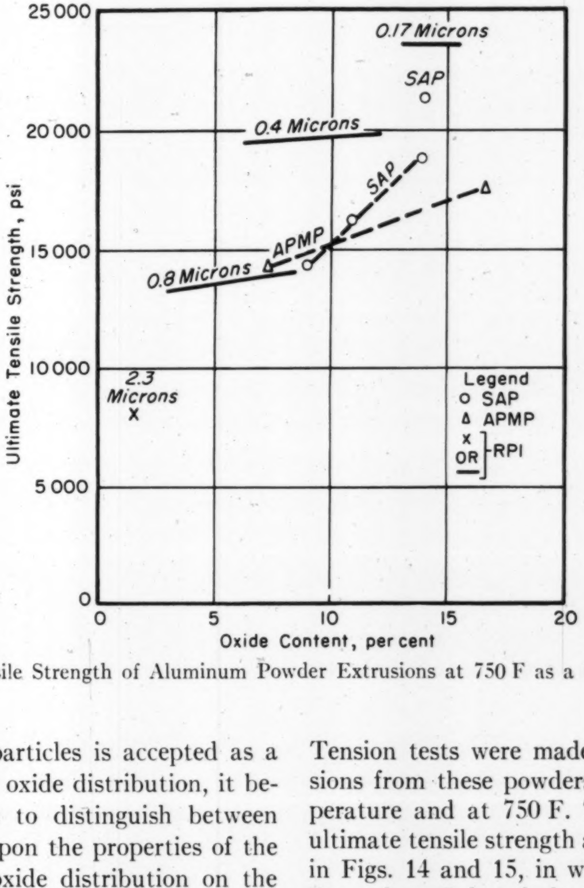

FIG. 14.—Tensile Strength of Aluminum Powder Extrusions at 750 F as a Function of Their Oxide Content.

Tension tests were made on the extrusions from these powders at room temperature and at 750 F. The results for ultimate tensile strength are summarized in Figs. 14 and 15, in which data from Rensselaer Polytechnic Inst. on specimens from four different experimental grades of SAP and two grades of APMP are also included. Figure 14 shows a plot of 750 F tensile strength *versus* oxide content. The data for the extrusions made at RPI lie on four essentially vertical levels corresponding to the four flake thicknesses, 2.3, 0.8, 0.4, and 0.17 μ, of the five grades of powder investigated. Within at least two of these levels, those for the 0.8 and the 0.4 μ powders, the oxide contents vary widely but have apparently little influence upon the 750 F tensile strength of the extrusions. In the case of the SAP and the APMP extrusions, nothing can be said about the flake thickness of the original powders, but the results on these extrusions confirm the impression that it is not the oxide content but the oxide distribution which determines the 750 F strength of the extrusion. No such clear-cut conclusions can be drawn from the room-temperature data shown in Fig. 15. The tensile strength at this temperature appears to be influenced by both oxide content and oxide distribution, since there is a definite increase in strength with increasing oxide content even for extrusions made from the powders of the same flake thickness.

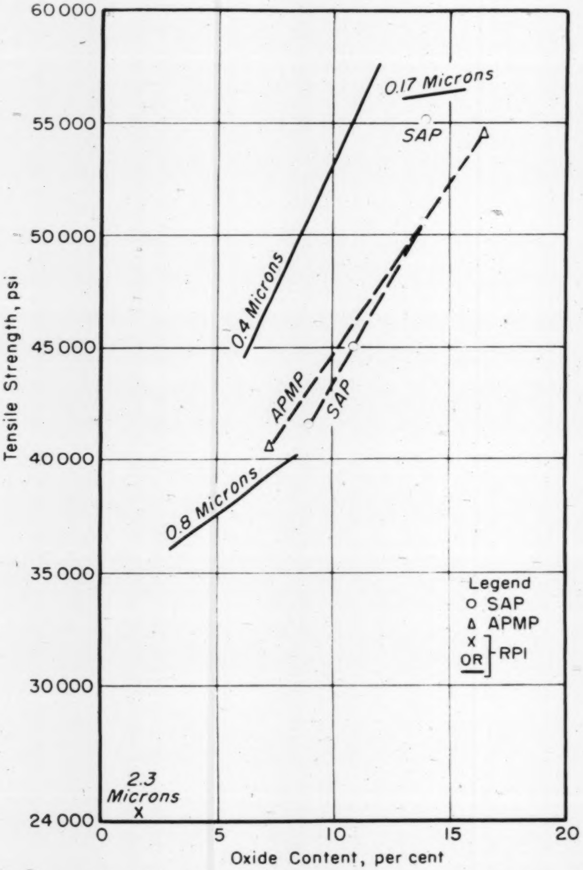

FIG. 15.—Tensile Strength of Aluminum Powder Extrusions at Room Temperature as a Function of Their Oxide Content.

It must be admitted that the relationship between oxide distribution and flake thickness is rather indirect. However, the oxide particles are so small that they cannot be seen under the light microscope. The only way to show them is by electron micrography. It is difficult to get reliable results by this technique, which has been tried at Massachusetts Inst. of Technology and is now being investigated at Rensselaer Polytechnic Inst. Eventually we hope at Rensselaer to confirm our conclusions about oxide distribution, based on the indirect flake thickness method, by more direct electron micrography. This should help in shedding light on one of the most interesting problems with regard to the new technique. Is it possible to produce alloys containing an insoluble second phase from base metal powders other than aluminum which have high strength at temperatures near their melting point?

TABLE XI.—TYPICAL PROPERTIES OF MAGNESIUM-ZINC-ZIRCONIUM (DOW ZK 60A) ALLOY EXTRUSIONS.

	Elongation in 2 in., per cent	Tensile Strength, psi	Tensile Yield Strength, psi	Compressive Yield Strength, psi	Ratio of Compressive to Tensile Yield Strength
As extruded from cast billet	14	49 000	38 000	33 000	0.87
As extruded from powder ("pellet extrusion")	17	50 000	39 500	41 000	1.04

PELLET EXTRUSION OF MAGNESIUM ALLOYS

Techniques for producing semifabricated products of superior properties from powders have also been developed for two other metals of low density—magnesium and beryllium. In the case of magnesium, it is again extrusions which have been produced from powder. The powders in this case have the composition of magnesium alloys rather than pure magnesium and are produced by atomizing magnesium alloys. The diameters of these spherical magnesium alloy powder particles are relatively large, averaging 350 μ. Because of the coarseness of the powder, Dow Chemical Co., the originators of this development (**19**), have chosen to call these extrusions pellet extrusions rather than powder extrusions. Nevertheless, I believe we can claim pellet extrusion as one of the achievements of powder metallurgy. The technique of extruding magnesium powder is practically the same as that of extruding cast magnesium billets except that powder is used as the charge in the container of the extrusion press. The principal advantage of pellet extrusions, as compared with extrusions from cast billets, is their fine grain size. When a magnesium alloy is atomized, each powder particle will have a very fine cored dendritic structure due to the rapid chill during atomizing. This fine structure is preserved when the powder is extruded. Fine grain size is of prime importance in magnesium and magnesium alloys because it has a direct influence upon the mechanical properties of the material and particularly the ratio of compressive to tensile yield strength. Because of the characteristic mode of deformation of magnesium crystals, twinning under compressive loads and slip under tensile loads, coarse-grained magnesium alloys tend to have a compressive yield strength considerably lower than their tensile yield strength. By making the grain size very fine, this tendency can be counteracted, as shown by the values in Table XI which compares typical properties of extrusions made from the well-known Dow magnesium alloy ZK 60A. There is a definite improvement in the ratio of compressive to tensile yield strength when pellets rather than cast billets are extruded.

There are other potential advantages of magnesium alloy extrusions from powder rather than from cast billets. They have been clearly outlined by Busk and Leontis (**19**) but have not yet been utilized in commercial production. To mention only one, it is possible to extrude a mixture of two powders having different alloy compositions. The alloying ingredients in these two powders may be so chosen that they would be incompatible in a cast magnesium alloy. For instance, one of the powders may contain zirconium and the other aluminum. When both aluminum and zirconium are added to liquid magnesium, they form an intermetallic compound insoluble in liquid magnesium, which readily segregates. Magnesium-zirconium and magnesium-aluminum alloy powders can, however, be co-extruded. During the time while the extrusion is at elevated temperature, zirconium and aluminum will diffuse and wherever they meet precipitate as particles of the intermetallic compound. This precipitate tends to strengthen the alloy matrix, a phenomenon somewhat akin to precipitation hardening which Busk and Leontis have termed interference hardening.

BERYLLIUM POWDER METALLURGY

In the processing of beryllium, powder metallurgy methods have become the standard of fabrication. They have been described by Beaver (**20**). Beryllium is used almost exclusively in atomic energy applications, and the normal economic standards cannot be applied to it. Since no information has been published in the unclassified literature about any details of these applications, it is difficult to evaluate whether these methods of fabrication should be considered commercial, semicommercial, or purely experimental.

Commercially pure beryllium is difficult to cast into sound ingots. The ingots are porous, have large grain size, and poor machinability. Even in wrought beryllium, which is usually produced by extrusion and is characterized by a very pronounced anisotropy of mechanical properties, material extruded from beryllium powder compacts is superior to that extruded from cast billets.

Detailed data on the mechanical properties of beryllium fabricated by powder metallurgy have been published by Beaver and Wikle (**21**). The raw material is −200 mesh beryllium powder. To obtain this powder, beryllium pebbles are produced by reducing beryllium fluoride with magnesium, the pebbles are vacuum-cast into 50-lb ingots, the ingots are machined into chips, and the chips are ground in an attrition mill. Two fabrication methods appear to give optimum combinations of properties. The first is hot pressing of powder in a vacuum under a pressure of 100 to 200 psi at a temperature of 1920 F. This method can be used for compacts up to 750 lb in weight. The resulting material has a very fine grain size of the order of the particle size of the beryllium powder (15 to 20 μ) and random orientation in its grain structure. The second fabrication method is hot extrusion at 1850 to 2000 F of warm pressed (850 F) or hot pressed (1920 F) powder compacts. When compared with extrusions from castings, the rods extruded from powder compacts have a higher degree of preferred orientation, a finer grain structure, and inclusions that are finer and more evenly dispersed. The mechanical properties are highly anisotropic with elongations of 10 to 20 per cent in the extrusion direction; they provide the optimum combination of strength and ductility for fabricated beryllium.

POWDER ROLLING

The semifabricated products mentioned so far were produced by a hot working process, extrusion, forging, or hot pressing. In the conventional sequence of powder metallurgy operations, the forming step, which is compacting, is done at room temperature. The question arises whether this room temperature compacting step could not be modified so that semifabricated products could be produced directly from powder. This question was answered affirmatively by German investigators. Naeser and Zirm (22) studied rolling iron powder into strip, while Franssen (23) independently rolled copper and copper alloy powders. Later laboratory studies of powder rolling were made in England on copper powder (24) and in this country on stainless steel powder (25). The rolls of the rolling mill, in which the powders are rolled, may be arranged above each other as in conventional rolling practice, or they may be in a horizontal plane. The powder is fed into the gap between the rolls. The friction between the rolls and the powder pulls the powder into the gap where it is compacted; it emerges as a continuous strip. Varying the gap or clearance between the rolls will produce variation in the pressure applied to the powder and therefore in the density of the strip. A narrow roll gap is required for producing dense strip. Some control over the thickness of the strip is possible by controlling the amount of powder fed into the roll gap. Surface finish and speed of the rolls and particle size and shape of the powder also have some influence upon the density and thickness of the strip. The maximum thickness of high-density strip that can be rolled from a given powder depends, however, primarily upon the diameter of the rolls. For iron or stainless steel powder, 8-in. diameter rolls will produce strip up to 0.040 in. thick, whereas 36-in. diameter rolls will produce strip up to 0.180 in. thick. Copper powder, on the other hand, because it is softer and more easily deformed, will produce thinner strip; with 8-in. diameter rolls high-density strip up to 0.025 in. thick can be rolled. The rolled strip must then be sintered. Because of the high rate of continuous rolling of strip, the rate of sintering must be adjusted accordingly. Naeser and Zirm (22) have shown that rolled iron strip can be sintered in a matter of seconds if the sintering temperature is 2200 F and above. They suggested sintering by passing a current directly through the strip as particularly suitable for rolled strip. Even with a narrow roll gap, rolled and sintered strip will not be completely dense. If a strip with the same properties as strip rolled from ingots is desired, one or more rerolling and resintering steps are required. Strip is not the only product that can be rolled from powder; copper powder has also been rolled into wire rod, and attempts have been made to roll it into tubing.

The new technique of powder rolling has aroused great interest, and efforts are being made both in Europe and in this country (26) to exploit it commercially. In assessing its commercial feasibility, we must distinguish between rolling of products which cannot be produced by more conventional techniques and powder rolling as a technique competitive with rolling from cast ingots.

Included in the first category are alloys that cannot be rolled and are therefore at present not otherwise available in strip form but which may be fabricated by powder rolling. Transformer sheet alloys very high in silicon may belong to this group. Porous strip or sheet may be powder rolled. Studies on stainless steel strip from powder (**25**) appear to indicate that its structure has a lower degree of preferred orientation than strip rolled from cast ingots and may be useful for this reason.

In order to evaluate powder rolling as a competitive technique, the quality of the products rolled from powder must first be considered. This would include dimensional control, freedom from defects, and mechanical properties. Second, precise figures for the cost of the process are necessary. The first and possibly the most important item is the cost of the powder. As long as the metal in powder form demands a considerable premium over the price of the metal in ingot form, the economy of powder rolling appears doubtful. For copper, nickel, and cobalt, hydrometallurgical methods of producing the metals from ore or scrap have been developed (**27**) in which the metals are obtained in powder form. Combining this lower-cost method of making powder with the powder rolling technique for producing thin-gage copper strip for such applications as automobile radiators is being investigated.

Certain metals are produced from their ores not in the form of massive metals but as sponge—for instance, titanium and zirconium. Melting the sponge into ingots is relatively expensive, but the sponge can be readily crushed into powder. The suggestion has therefore been made (**28**) to apply powder rolling to titanium and zirconium.

Besides the cost of the raw material, the other items of cost—the actual rolling of the powder, sintering, rerolling, and annealing—must be considered in a cost analysis. Fewer passes should be necessary to roll strip from powder to the desired gage. On the other hand, the techniques of rolling strip from ingot have been made highly automatic and therefore relatively low in cost. My personal estimate is that powder rolling will become an important branch of the powder metallurgy technique in the years to come.

CERMETS

The role of powder metallurgy in the development of high-temperature materials has recently been described in an excellent review (**29**) by Ault and Deutsch of the Lewis Flight Propulsion Laboratory of the National Advisory Committee for Aeronautics, and I can therefore keep my discussion of these materials brief. The materials presently used, cast and wrought cobalt- and nickel-base alloys of the Vitallium type, have definite temperature limitations. Even for the best of them, the strength above 1600 F decreases rapidly, and there is little hope that variations in analysis will bring radical improvement. One avenue of approach to improved materials has been the refractory metals, in particular molybdenum and molybdenum alloys. Fifteen years ago, there would have been no question that these materials be included in a discussion of powder metallurgy. Today, however, molybdenum and its alloys are produced both by powder metallurgy and by arc-casting methods, and the powder metallurgist can no longer claim them as solely his own. I shall therefore limit myself to two brief observations on molybdenum and its alloys.

The classical method of fabricating molybdenum powder into wire or sheet, which is still of importance today, is the Coolidge method originally developed for tungsten, in which the powder is pressed into a long bar with a relatively small square cross-section of less than 1 sq in., presintered, and then sintered by passing an electric current through it. The sintered bar is then swaged and drawn or rolled into the final product. The size of the bar produced by this method is limited by the electrical requirements for resistance sintering. An alternate method for fabricating molybdenum powder into final products has been developed by Westinghouse Electric Corp. Compacts of much larger size are pressed from powder and sintered in furnaces, in which the compacts are heated by radiation from the heating elements in the furnace rather than by direct current passage. The sintered "ingots" are then further fabricated. The method is applicable also to molybdenum alloys and has minimized one of the principal drawbacks of the powder metallurgy method of fabricating molybdenum, the size limitation.

Tests have shown that molybdenum and particularly molybdenum alloys have excellent high-temperature strength, with stresses to rupture in 100 hr at 1800 F of over 20,000 psi for pure molybdenum and over 40,000 psi for some molybdenum alloys. The principal problem in applying molybdenum and its alloys to high-temperature use is their poor oxidation resistance. The answer to this problem will lie in protective coatings. It is obvious that the adequacy of a coating, be it an intermetallic compound, a ceramic, a metal, or an alloy, will depend on the application in which the coated component is being used—whether there are stresses present due to thermal cycling, whether high-speed impact is a problem, etc. For these reasons, it seems probable that eventually a variety of coatings for molybdenum and its alloys will come into use which are specifically tailored to the application.

A second approach to improved high-temperature materials lies in a class of materials for which no adequate name exists at the present time. This class of materials includes first intermetallic compounds, such as the aluminides of nickel, titanium, and zirconium, and certain titanides. Second, it includes compounds of the transition metals, titanium, vanadium, chromium, zirconium, columbium, molybdenum, hafnium, tantalum, and tungsten, with the metalloids carbon, nitrogen, boron, and silicon. These carbides, nitrides, borides, and silicides have, in general, the high thermal and electrical conductivity of metals, high melting points and good stability at elevated temperatures, high hardness and strength, but quite limited toughness. Finally, this class includes combinations of metals and alloys with a variety of chemical compounds ranging from the strictly "ceramic" oxides of aluminum, magnesium, beryllium, zirconium, and the nonmetallic carbides of silicon and boron to the more or less metallic carbides, nitrides, borides, and silicides of the transition elements. This group of combination materials is generally called "cermets," but it is not practical to draw a sharp line of demarcation between these combinations and the pure compounds described above. In a loose and admittedly lexicographically incorrect way, all three groups have been called "cermets," and I shall use the term in this sense here.

The cermets form a curious twilight zone between ceramics and metallurgy, and both ceramists and powder metallurgists have been active in their development. The methods of fabricating the raw material in the form of powders into finished components have run the gamut from the powder metallurgical technique of cold pressing and subsequent sintering through hot-pressing to the strictly ceramic technique of slip casting and firing. The same goes for the methods for testing the materials.

A screening test for the high-temperature strength of cermets is usually the transverse rupture strength test of the ceramists. However, transverse rupture strength data are generally insufficient for evaluating the strength properties of these materials, and the methods developed for high-temperature alloys have been applied to the cermets. In particular, the stress to rupture in 100 hr at 1600, 1800, 2000 F, and higher has been widely used to compare different cermets. Elevated-temperature fatigue strength tests have also been recently applied to cermets. A problem well known to ceramists, that of thermal shock sensitivity, is also one of the principal problems in cermets. Because of the complex way in which several fundamental properties of a material influence its thermal shock behavior, only empirical tests in which specimens of a definite size and shape are tested are available for cermets. Two of these tests, developed by the National Advisory Committee for Aeronautics and by Wright Air Development Center, permit accurate grading of different cermet compositions and correlation with the actual thermal shock requirements in such critical components as turbine blades. Cermets must have adequate oxidation resistance at high temperature, and the same tests applied to alloys are applied to cermets. Finally, a test for toughness, or more accurately impact strength, of cermets has been devised by modifying the standard Izod test. In the Izod test a specimen is broken by the impact of a hammer of constant weight dropped from a constant height. The energy absorbed in breaking the specimen is measured. In the modified test the specimen is struck repeatedly by blows of a hammer from gradually increasing heights. The energy just sufficient to break the specimen is measured. This eliminates the so-called "toss energy," which is the kinetic energy imparted to the fragments of the test specimen by the impacting hammer. It is, however, uncertain whether even this test is a good measure of what is required in turbine buckets, namely, resistance to failure when gravel or fragments from a previously failed bucket strike a bucket.

The fundamental problem in designing cermets for aircraft propulsion applications is to preserve as much as possible of the excellent high-temperature strength and oxidation resistance of the pure oxide ceramics and, on the other hand, provide adequate thermal shock and impact resistance. In general, it has been found that the greater the high-temperature strength of a cermet the more difficult it is to retain its resistance to thermal and mechanical shock. Two types of materials, the aluminum oxide-chromium metal cermets and their variations and molybdenum disilicide, have substantial strength even up to 2000 F, where the cemented titanium carbides, which will be discussed later, loose strength rapidly, but they are deficient not only in impact strength but also in thermal shock resistance. On the other hand, molybdenum disilicide has excellent oxidation resistance and an electrical resistivity which advocates its use as a superior material for electric furnace heating elements. The investigation of metal borides and metal aluminides has not yet advanced far enough to locate them definitely in the scale of properties.

By far the greatest amount of research and development work in cermets has been applied to cemented titanium carbides. These materials developed logically from cemented tungsten carbides, which are well known for their use as cutting tools and for wear-resistant applications. Cemented tungsten carbides and their variations, which include minor amounts of titanium and tantalum carbides, are fabricated by ball-milling together the carbide powder and the binder metal powder, generally cobalt, pressing the powder mixture either into its final desired shape or into a blank, and sintering the compact in two or sometimes more steps, which include presintering and final sintering.

TABLE XII.—HIGH-TEMPERATURE STRENGTH OF VARIOUS CEMENTED CARBIDE COMPOSITIONS.

Manufacturer	Grade Designation	Binder Metal, per cent	Binder Metal Composition	Carbide Composition	Density, g per cu cm	Stress to Rupture in 100 hr, psi	
						1600 F	1800 F
Kennametal Inc.	K163B	40	Ni-Mo	TiC + (Cb, Ta, Ti)C	6.28	31 000	12 000
	K164B	50	Ni-Mo	TiC + (Cb, Ta, Ti)C	6.61	29 000	10 000
	K173B	40	Ni-Mo-Al	TiC + (Cb, Ta, Ti)C	6.09	44 500	17 500
	K174B	50	Ni-Mo-Al	TiC + (Cb, Ta, Ti)C	6.38	42 000	15 500
	K175B	60	Ni-Mo-Al	TiC + (Cb, Ta, Ti)C	6.66	39 000	16 000
Metallwerk Plansee	WZ12b	40	Ni-Co-Cr	TiC	6.25	...	17 000
	WZ12c	50	Ni-Co-Cr	TiC	6.55	31 000	14 000
	WZ12d	65	Ni-Co-Cr	TiC	6.95	25 000	11 000
Firth Sterling Inc.	FS26	40	Ni	TiC + Cr_3C_2	6.25	21 000	11 000
Sintercast Corp. of America	TC-661	TiC skeleton infiltrated with nickel-base alloy			6.01	38 000	16 000
	X-40	25 Cr, 10 Ni, 8 W, 0.5 C, balance Co			8.61	21 000	11 300

Cemented tungsten carbides are not satisfactory high-temperature materials, primarily because of their poor oxidation resistance at temperatures above 1200 F. Their high density, between 12 and 15 g per cu cm, also stands in their way for applications where centrifugal stresses are involved. The fabrication of cemented titanium carbides follows in general that of cemented tungsten carbides. For any but the simplest shapes, a blank is pressed from the powder mixture. Whenever intricate components are to be machined from the blank, it is important that it have an even density distribution, because the density of the green and presintered compact controls the amount of shrinkage during final sintering. The best method of obtaining even density is hydrostatic pressing. The blanks are presintered to the consistency of chalk and are then strong enough to be given their final shape by turning with diamond-tipped tools or machining with abrasive wheels. Proper allowance is made for shrinkage during final sintering, which amounts to several per cent linearly. Through cooperation between cemented carbide fabricators and machine tool builders, methods have been developed for forming on multiple-head automatic machines very intricate twisted and tapered airfoil shapes with attached base and even complete turbine wheels with integral buckets. After forming, the components are given a final sintering treatment in a high-frequency induction sintering furnace under a vacuum of a few microns. Forming after final sintering is held to a minimum because of the difficulty of grinding the very hard cemented titanium carbides.

Cemented titanium carbides with cobalt or nickel as binders have densities between 5.5 and 7 g per cu cm depending on the binder metal content, which makes them 35 to 20 per cent lighter than the cobalt- and nickel-base high-temperature alloys. By themselves, they do not have adequate oxidation resistance at 1500 F and above, but minor variations in analysis have remedied this deficiency. Small amounts of columbium and tantalum carbide, generally less than 10 per cent, may be added to the carbide phase, or chromium may be added either as an alloying element in the binder phase or as chromium carbide. The resulting compositions are adequately oxidation resistant. The thermal shock resistance of all the cemented titanium carbides is quite good. The high-temperature strength of various cemented titanium carbide compositions (30) is illustrated by the data in Table XII, which show typical values for stress to rupture in 100 hr at 1600 and 1800 F for a series of compositions produced by different fabricators. The corresponding stress to rupture values for one of the best cast cobalt-base alloys, X-40 or Haynes Stellite No. 31, are also shown. In making the comparison between the cemented titanium carbides and the cobalt-base alloy, the higher density of the alloy should be remembered. In applications where the stress is centrifugal, not the stresses to rupture themselves but the ratios of stress to density should be compared. Considering this ratio, all of the cemented carbides are definitely superior to X-40.

When different grades of cemented carbides are compared, it is well to keep in mind the principal deficiency of cemented titanium carbides, at least as far as their use in turbine blades is concerned. This is their low impact strength, which is only of the order of a few per cent of that of high-temperature cobalt-base alloys. Table XII indicates that increasing the amount of binder generally decreases stress to rupture. But, on the other hand, increasing the binder content increases the impact strength. Impact values for WZ12c are only two thirds and for WZ12b less than one half those of WZ12d. In order to compensate for the lower strength, which is the corollary of higher binder content, the composition of the binder alloy may be adjusted to make it in itself stronger, as was done in the K170 series as compared with the K160 series. The ultimate aim must be the highest impact strength with minimum sacrifice in stress to rupture. Another approach to increased impact strength was taken in a group of materials of which TC-661 is an example. These cemented titanium carbides were produced by infiltrating a sintered porous sponge of titanium carbide with a nickel-base high-temperature alloy. The infiltrated materials appear to have somewhat improved impact strength compared with the materials produced by sintering alone. The problem of adapting titanium carbides to use in turbine bucket applications is not merely one of developing compositions or fabrication methods for the purpose of producing tougher materials; it is at least as much a problem for the designer, who must adapt his design to inherently brittle materials. After all, increased shock sensitivity will be the price we will have to pay for materials of increased high-temperature strength. This goes not only for the cemented titanium carbides, but for all the other cermets too.

I feel that the very great interest in these high-temperature materials justified my discussing them, even though their use for turbine buckets, for the less highly stressed nozzle vanes, and for components in nonaircraft gas turbines is still in the development stage. This does not mean, however, that all of the new high-temperature materials, and particularly the cemented titanium carbides, are merely laboratory curiosities. Successful commercial applications

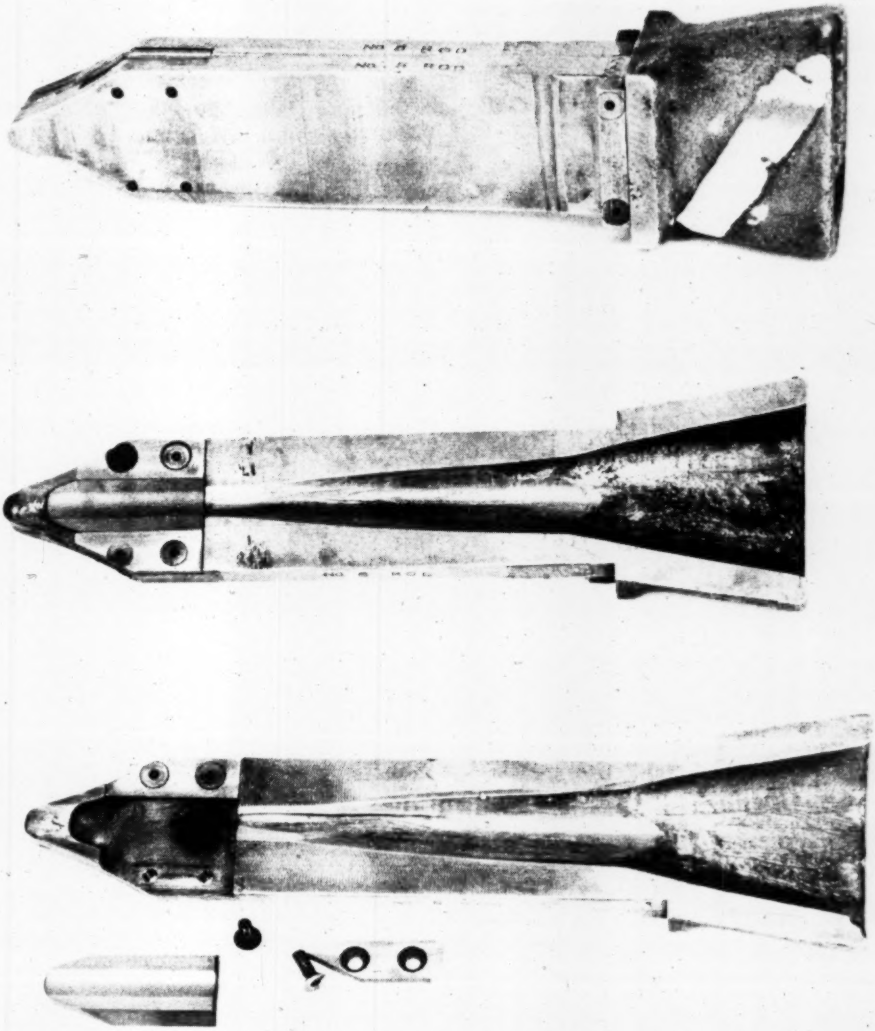

FIG. 16.—Rod Mill Guides with Inserts Made of Cemented Titanium Carbide.

for cemented titanium carbide are illustrated in Figs. 16 and 17. In Fig. 16 inserts for rod mill guides, used in hot-rolling of rod, are shown. The guides are made of bronze. Without inserts the guides wear out rapidly in about one shift, whereas guides equipped with cemented titanium carbide inserts will stand up for several thousand hours. In this application, advantage is taken of the excellent combination of wear and oxidation resistance of the cemented titanium carbide. The same properties are of value in the application shown in Fig. 17, pinch jaws that pinch off and seal the glass tube through which the sealed beam headlight lamps are evacuated. Again, because of the wear and oxidation resistance of cemented titanium carbide, these jaws have outlasted jaws from other materials that had been tried.

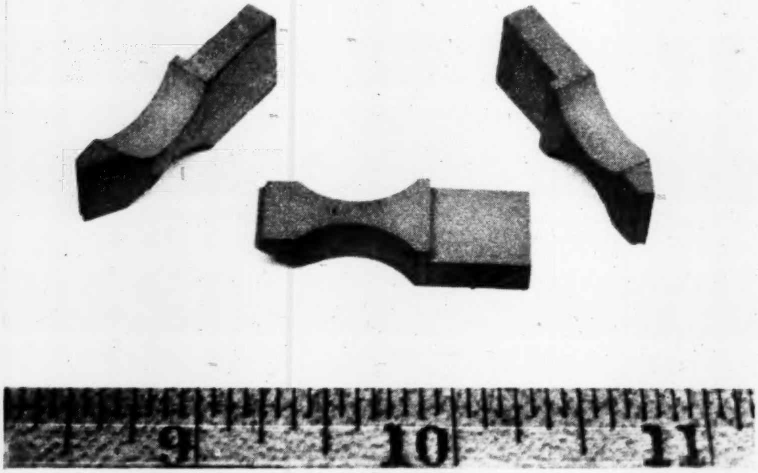

FIG. 17.—Pinch Jaws for Sealing Sealed Beam Headlight Lamps Made of Cemented Titanium Carbide.

TRANSPIRATION-COOLED MATERIALS

The problem of finding suitable materials for aircraft propulsion applications, where components have to operate at high stresses in contact with gas streams having temperatures of 1500 F and above, has been approached in another way. This approach involves cooling the component. Powder metallurgy may play an important role in the fabrication of cooled components because it permits producing materials of controlled porosity and permeability.

Such porous and permeable materials can be cooled by transpiration cooling. In this method, the coolant is passed from the cool side of the component through its pores to the side of the component which is heated by contact with the hot gases. On this hot side of the component, the coolant provides an insulating and protective film. Transpiration cooling has been found to be considerably more efficient than more conventional methods of cooling, for example, conduction. Both liquids and gases have been considered as coolants in transpiration cooling, which has been proposed for components in rocket engines and in various types of jet engines such as ram-jet and turbojet engines. Turbojet engine applications would include afterburner housings, stationary nozzle vanes, and turbine blades. In the last of these applications, transpiration-cooled turbine blades, air is the coolant that has been generally suggested. These blades present particular difficulties, because centrifugal stresses are high, and their design, usually a twisted and tapered airfoil shape with attached base, is difficult to produce in a porous material of controlled permeability. Nevertheless, transpiration cooling would be attractive for this application because calculations have shown that for gas stream temperatures of 2500 to 3000 F, which are projected for future designs, a given decrease in blade temperature can be accomplished by transpiration cooling with one third to one half the amount of cooling air which would be needed to obtain the same cooling effect with conventional cooling. Considerable development work on transpiration-cooled turbine blades has therefore been done.

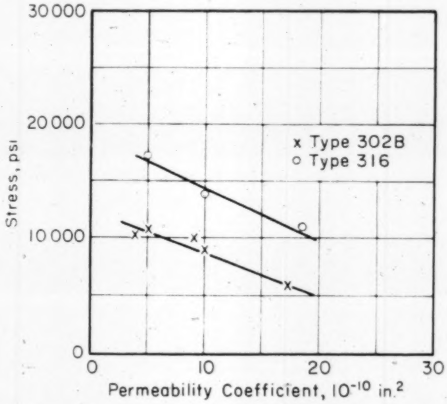

FIG. 18.—Stress to Rupture in 500 hr for Porous Stainless Steel Specimens as a Function of Their Permeability.

The permeability of a porous material is that property which determines how much coolant of a given viscosity will pass through a unit cross-section and unit thickness of the material under a given pressure gradient. Permeability is important because the cooling effect is a direct function of the amount of coolant passing through the material. For relatively low rates of flow where so-called laminar flow prevails, the permeability can be expressed according to Darcy by a single parameter, the permeability coefficient, expressed in square inches, which is independent of coolant flow rate and viscosity and section thickness. For higher flows, equivalent permeability coefficients may be substituted. Porosity in itself is not a good measure for permeability, since different materials may have the same porosities but vary widely in permeability, particularly when they are made from different mesh fractions of a powder and therefore differ in the size of their pores.

A first design possibility for a transpiration-cooled turbine blade would be to make the blade not only porous but also hollow and pass cooling air, which has been bled from the compressor, through passages in the turbine wheel into the cavity of the blade and from there through the porous structure of the blade. The design requires that the blade material have a permeability large enough so that the blade is cooled to a temperature well below that of the gas stream in which it operates. At the same time, it must have sufficient strength so that the blade will withstand the centrifugal stresses to which it is subjected in operation at the temperature to which it is cooled. A series of tests were made at Rensselaer Polytechnic Inst., on the basis of a development contract with the Navy Bureau of Aeronautics, in which the stress-rupture properties of a number of porous materials were determined as a function of their permeability (**31**). Stress to rupture at 1100 F, rather than room-temperature tensile strength, was determined because, with the limited amount of cooling air available, it is expected that the temperature of the cooled blades will reach 900 to 1100 F. Stress-rupture samples were prepared by compacting and sintering type 302B (18 per cent chromium - 8 per cent nickel - 2 per cent silicon) and type 316 (18 per cent chromium - 12 per cent nickel - $2\frac{1}{2}$ per cent molybdenum) stainless steel powders. By varying compacting pressure and mesh-size fraction of the powders, the permeability coefficient of the specimens was varied in the range of interest for transpiration-cooled blades from 3 to 12×10^{-10} sq in. For each permeability a sufficient number of specimens was tested under varying stresses so that the usual log stress *versus* log time to rupture curves could be drawn. From these curves values for stress to rupture in 500 hr were interpolated and plotted *versus* permeability coefficient as shown in Fig. 18.

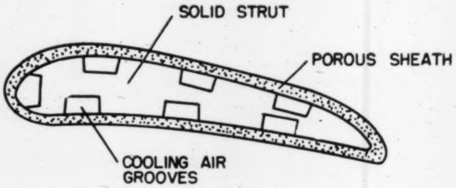

FIG. 19.—Schematic Sketch of a Transpiration Cooled Turbine Blade Consisting of a Solid Strut and a Porous Sheath.

It will be seen that the stresses to rupture in 500 hr at 1100 F are relatively low—17,000 psi at 5×10^{-10} sq in. permeability coefficient for compacts from 316 stainless steel powder and 11,000 psi at 5×10^{-10} sq in. permeability coefficient for 302B stainless steel powder. It would probably be possible to obtain somewhat higher values with more highly alloyed powder. Nevertheless it is doubtful whether strong enough blades could be made with a design in which the entire blade is made from a porous material.

Suggestions for an alternate blade design have been made both in England (**32**) and in this country. According to this design, a schematic sketch of which is shown in Fig. 19, the blade would consist of a solid nonporous strut with grooves in the spanwise direction. The solid strut, which would be made of a cast or wrought material, would carry the centrifugal stress and would be surrounded by a porous sheath fastened to the strut. This sheath might be fabricated from powder, although other porous materials are also under consideration. The coolant air would be conducted into the grooves and would pass from them through the porous sheath, thereby cooling the blade to the desired extent.

The fabrication of transpiration-cooled turbine blades presents difficult problems which challenge the ingenuity of the powder metallurgist. Many of the problems have not yet been solved, and I present these blades as an example of one of the possible powder metallurgy applications of the future.

CONCLUSION

In presenting this fourth Gillett Memorial Lecture, it has been my intention to point out some of the great potentialities of the powder metallurgy process. In doing so I have tried to preserve that critical attitude which Dr. Gillett demanded of the engineer and scientist. I hope that those of you who were his friends and coworkers feel that this lecture would have met with his approval.

In closing, I should like to express my sincere appreciation to the people and the organizations who supplied me with the examples of powder metallurgy products which were so essential to the preparation of this lecture.

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EFFECTS OF NEUTRON IRRADIATION IN STEEL*

By J. C. Wilson[1] and R. G. Berggren[1]

Synopsis

Mechanical test results were obtained for carbon and austenitic stainless steels that had been subjected to integrated fast neutron fluxes of 10^{19} to 10^{20} nvt. The results generally confirm data obtained by others; but certain peculiarities of behavior were observed during the testing program. The shape of the stress-strain curve for austenitic stainless steels is altered, and with sufficient irradiation, or a high enough testing speed, the metals showed definite yield points. In addition, the yield stress of the irradiated austenitic stainless steels was found to depend strongly on the strain rate.

In carbon steels, irradiation sometimes eliminated the yield point and decreased the ductility to a greater extent than in austenitic stainless steels. Annealing of irradiation effects in carbon steels during irradiation at elevated temperatures was found to exert varying degrees of influence on different mechanical properties. Notch-bar impact tests on the carbon steels showed the effect of irradiation on the transition temperature. There appears to be strong evidence that irradiation can cause structural metals to behave in a manner sufficiently different from unirradiated metals that a new concept of the relationships between mechanical test results and service performance must be formulated in evaluating metals for service in nuclear reactors.

It is now well established that neutron irradiation can alter the mechanical properties of metals. Conventional mechanical testing procedures provide numerical values for the changes of strength and ductility produced by neutron irradiation. But neutron bombardment of a metal can introduce changes in the structure that cannot be duplicated by alloying, heat treatment, or deformation; and the irradiated metal is therefore in a state or condition outside our normal metallurgical experience. For this reason, the interpretation of mechanical test results obtained for irradiated metals is not clear, and we cannot assume that the existing relationships between results from standardized mechanical tests and service performance will be the same as for an unirradiated metal.

This paper presents data on the effects of irradiation on the ductility, strength, and mechanical test behavior of a group of irradiated austenitic stainless steels and several carbon steels. From these results it is concluded that irradiation can alter the behavior of these metals to such an extent that existing materials specifications may not be applicable to metals that will be subjected to neutron bombardment in service.

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* Presented at the Fifty-eighth Annual Meeting of the Society, June 26–July 1, 1955.

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HISTORY

About five years ago, Billington and Siegel (**1**)[2] first reported, in the unclassified literature, some effects of neutron irradiation on metals. In 1954 Leeser (**2**) presented the first large compilation of data on the effects of irradiation on both mechanical and physical properties of a large number of engineering alloys.

During the past five years perhaps 100 publications have dealt with specialized investigations on the many aspects of radiation effects in metals. Blewitt and his colleagues have described ordering and disordering of the Cu_3Au superlattice by neutron bombardment (**3**); the same authors have studied the effects of irradiation on the yield strength (**4**) and twinning (**5**) in copper single crystals. Taylor and Murray (**6**) reported the effects of irradiation on the aging of precipitation-hardenable alloys. Effects of irradiation on creep behavior were described by Witzig (**7**), Yockey, *et al.* (**8**), Makin (**9**), and Jones (**10**). The ductility changes in irradiated molybdenum were recently studied by Bruch and coworkers (**11**). The effect of irradiation on the ferrite content of type 347 stainless steel was described by Reynolds (**12**). Kunz and Holden (**13**) showed the effects of neutron irradiation on single crystals of lead, zinc, and iron. This brief listing gives some idea of the range of properties that have been studied. Nowhere, however, has an attempt been made either to assess the importance of the neutron-induced property changes in engineering materials or to inquire into the engineering significance of the differences between irradiated and unirradiated metals.

BRIEF THEORY OF RADIATION EFFECTS

Space limitations will permit only a brief description of the theory of radiation effects in metals. Several review papers are available for those interested in a more complete discussion (**14**, **15**, **16**). Neutron irradiation can cause several phenomena to take place in the irradiated metal simultaneously; the ultimate result will depend on the magnitude of each effect, and this in turn is a function of the state of the metal and the temperature.

Probably the most important cause of irradiation effects in metals is the production of vacancies and interstitial atoms in the metal lattice by collision, directly and indirectly, of high-energy neutrons with the atoms of the lattice. In the data to be presented here it is probable that the great bulk of the effects of irradiation are the results of collision-produced interstitial atoms, and possibly vacancies, or separate agglomerations of either type defect. Increased diffusion rates on an atomic scale are believed to be the result of the increased concentration of vacancies, so that diffusion-dependent metallurgical reactions may occur more rapidly under irradiation. At sufficiently high temperatures, the vacancies or interstitial atoms, or both, will have sufficient mobility to recombine, annihilate, or anneal, as it is commonly called.

A "thermal spike" concept is used to explain certain effects of neutron irradiation. In a metal crystal an atom receiving a large amount of energy from an incident neutron will impart some of this energy to perhaps 10,000 atoms along its path and excite them to energy levels equivalent in temperature to the melting point. Because of the relatively good thermal conductivity of metals, this energy is dissipated in a very short time, perhaps 10^{-10} sec. In effect, a small region of the lattice is heated and cooled very rapidly. The thermal spike concept has been used to explain the disordering of metals in which a superlattice exists (Cu_3Au or Ni_3Cr). Electrical resistivity of the superlattice is very sensitive to changes in the degree of order, and relatively small amounts of irradiation are capable of causing sufficient disorder to be readily measured. These phenomena have received considerable study (3).

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[2] The boldface numbers in parentheses refer to the list of references appended to this paper, see p. 706.

Since neutrons are capable of causing transmutations from one element to another, exposure to intense neutron bombardment for a sufficient period can cause appreciable, and even important, changes in the composition of an alloy. In general the amount of neutron irradiation received by samples whose properties are described here was insufficient to cause composition changes of importance.

Neutron Flux Units and Magnitudes:

The effects of neutron irradiation in metals is strongly dependent on the energy of the incident neutrons. Neutrons emitted in the fission process have energies on the order of 1 to 10 Mev (million electron volts). In nuclear reactors classified as thermal reactors the fission process is mainly caused by "thermal" or "slow" neutrons that have had their energy reduced to perhaps 0.025 ev by collisions with other atoms. The slowing down of the neutrons in a typical thermal reactor is accomplished by collisions with the atoms of the moderator (graphite, beryllium, or water). Since the neutrons are born with high energies, even in a thermal reactor, there will be fast neutrons in the neighborhood of the fissioning fuel. As a result, neutrons of a wide range of energies will be found in varying amounts depending upon the location in the reactor.

In a "fast" reactor, fission is caused mainly by fast neutrons with energies of the same order as that at birth. In a fast reactor, the structural materials will be exposed only to fast neutrons.

Displacing a metal atom from its lattice site requires about 25 ev. Depending on the mass of the atom displaced, a neutron energy of the order of 1000 ev is required. It is important to know the energy of the neutrons incident upon a structural material that is being irradiated in order that results from different tests may be intercompared. Unfortunately it is a tedious task to measure the neutron spectrum in a reactor; furthermore it is not yet well known what are the relative effects of different ranges of high energy or fast neutrons.

The rate of neutron bombardment of a specimen is termed the neutron flux. The present general method of reporting neutron fluxes is to give the thermal neutron flux (about 0.025 ev) and the fast neutron flux above some threshold energy, usually 1 Mev. Flux measuring techniques are continually being improved, but it will probably be several years before all experimental irradiation effects work is reported in a uniform manner. As a general rule thermal flux data may be relied upon, but, unless details of measurement are given, fast flux values are generally doubtful.

Since it is believed that most effects on mechanical properties of metals at relatively low neutron dosages are caused by fast neutrons, it is with the fast neutron flux that we will be concerned. Thermal neutron fluxes are important where transmutation effects may be seen, but the irradiations of materials described in the unclassified literature generally are insufficient to cause discernable transmutation effects.

The neutron flux is the term used to describe the rate of bombardment of a specimen. The neutron flux is expressed in units of neutrons per square centimeter per second; the flux may vary from 10^6 neutrons per sq cm per sec at a laboratory polonium-beryllium neutron source to 10^{14} neutrons per sq cm per sec in the Materials Testing Reactor (17). The neutron flux multiplied by the time gives the total exposure to neutrons; this is called the "integrated flux" and is given in units of neutrons per sq cm or nvt. The neutron flux or integrated flux will usually be given separately for both thermal and fast neutrons.[3]

Values for integrated flux, or neutron dosage alone may not be sufficient to describe the history of an irradiated specimen. Since annealing of defects introduced into a specimen by irradiation takes place as a function of time and temperature, a specimen irradiated at a low flux for a very long time may be in a different condition than a specimen irradiated to the same integrated flux by exposure to a high flux for a proportionately shorter time. Therefore both the neutron flux and integrated flux should be reported. At present there is little quantitative data on these relationships.

Specimens tested by Leeser and Sutton and by the authors were exposed to maximum fast neutron fluxes of about 10^{14} neutrons per sq cm per sec and maximum fast neutron integrated fluxes of about 10^{20} nvt. Power reactors may be expected to expose structural materials to maximum fast neutron fluxes perhaps two orders of magnitude greater than is available to the experimenter today. In addition, the life of such a reactor will be expected to be at least several years and it is therefore difficult to obtain adequate experimental data. The investigations to date cannot be expected to predict, reliably, effects that may become important at fluxes an order of magnitude greater or integrated fluxes more than two orders of magnitude greater, but these investigations indicate at least some of the effects which must be considered in evaluating materials for use in future, high power nuclear reactors for extended periods of time.

Difficulties of Irradiation Effects Studies:

The over-all study of radiation effects in metals is expensive, tedious, time consuming, and often frustrating. The radioactivity in test specimens that have been irradiated usually necessitates testing by remote control in a "hot cell" or "cave." Such a hot cell may have dense concrete walls 3 ft thick, a high-density window of the same thickness, and various types of manipulators to extend the experimenter's hands into the cell. The experimenter will be perhaps 5 ft from his test apparatus, and his sense of touch, manual dexterity, and patience will be adversely affected by being obliged to use manipulators that, at best, are poor substitutes for human hands. Performance of a given test in a hot cell may require from 2 to 50 times as much time as the same test performed in a normal testing laboratory. A series of papers, recently published, was devoted to hot-cell techniques (18).

Irradiation of test specimens is not simple. The intense radiation levels in a nuclear reactor may cause severe internal heating in test specimens, and gradients in this heating and in the neutron flux make it difficult to irradiate more than a few specimens at the same temperature and neutron flux. Space in the highest flux regions of present reactors is severely limited, and the experimental apparatus must be small. Irradiations carried out on the specimens described in this paper were conducted in a container about 4½ in. in diameter and about 10 in. long.

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[3] All values of neutron flux and integrated neutron flux reported in the data and discussion sections of this paper are for fast neutrons of energy greater than 1 Mev unless otherwise noted.

Even then the specimens at one end of the apparatus received 5 to 10 times as much neutron dosage as at the other end.

Experimental Procedure:

Irradiations were carried out in the Low Intensity Testing Reactor (LITR) at Oak Ridge, Tenn. and the Materials Testing Reactor (MTR) (17) near Arco, Idaho. The neutron flux in the MTR is about 10 times that in the LITR. All specimens irradiated at the MTR were either in cooling water or in contact with aluminum tubes containing cooling water. The measured maximum temperature reached by any specimen during irradiation was 195 F, with the exception of certain carbon steel specimens maintained intentionally at 570 F (±10 F).

All of the tension test and notched bar impact test specimens were made smaller than standard size because of self-heating limitations imposed by reactor conditions and to permit the simultaneous irradiation of the maximum number of specimens.

Hardness testing prior to irradiation was carried out on a conventional Rockwell hardness testing machine; the hardness of the irradiated samples was determined on the same machine by placing it in a hot-cell and operating the unmodified machine by remote manipulators. Rockwell hardness tests made in a cell in this manner require about 2 min per test.

Tension testing was carried out in a constant crosshead speed machine with a "hard," electronic weighing system. The deflection of the weighing system and auxiliaries at the loads used was about 0.005 in. A remotely controlled extensometer (19) was used to obtain load-elongation diagrams on an X-Y recorder. Square and round shank, unthreaded specimens of several shank sizes were used; the gage length was 1 in. and the diameter 0.180 ± 0.001 in. Gripping was accomplished by double-acting air cylinders that actuated 10,000-lb capacity Templin grips. Actual test time for an irradiated specimen averaged only about 5 min longer than for a test conducted outside the hot cell, exclusive of time for diameter measurements.

Elongation was not measured between the usual gage points. The manipulators at our disposal do not have the touch, or perhaps the authors did not have the patience, to try to fit together broken specimens in which the fracture diameter is only about 0.1 in. The minimum diameter and the elongation at maximum load were measured by holding the specimens on the end of a cantilevered arm extending through a small hole in the side of the hot cell. The end of the arm protruding outside the hot cell was mounted on a rugged micrometer movement that could be read to 0.0001 in. Readings on the micrometer base were then made when the extremes of the specimen passed a reference line in a surveyor's transit mounted at the hot-cell window. Readings (in duplicate) of the minimum and average diameter of each specimen require about 20 min in this manner.

Notched bar impact tests were conducted in a modified Plastics Impact Machine (20) using subsize Izod type specimens to conserve irradiation space. The specimens were multiple notch bars 0.2 in. square with notches 1.10 in. apart along the bar. The notches were 0.06 in. deep with a 45-deg included angle and a 0.005 in.-root radius. The specimens were brought to test temperature while clamped in the vise of the testing machine. Test temperatures above room temperature were achieved by heating the entire anvil of the testing machine with electric heaters of 1500-w capacity. Test temperatures below room temperature were obtained by cooling the anvil and specimen with liquid nitrogen. Each test requires an average of about 20 min.

The impact tests conducted at and above the transition temperatures did not yield complete fractures, and considerable scatter occurred in the energy data. The subsize specimens described above had been satisfactory in previous tests on some other steels. But the greater toughness of the steels used in this study, together with the small specimen size, resulted in incomplete fracture in many of the tests. Therefore measurements were made of the maximum specimen contraction at the fracture face. These measurements were made by mounting the fractured specimen in the hot cell on a rugged micrometer movement that could be read to 0.0001 in. Readings on the micrometer movement were made when the fracture edges at maximum contraction coincided with a reference line in a 20× periscope system. Both fracture faces were measured by this means where possible, and the average maximum contraction was plotted against the testing temperature.

TABLE I.—MECHANICAL PROPERTIES OF IRRADIATED AND UNIRRADIATED AUSTENITIC STAINLESS STEELS.

Irradiation Temperature less than 200 F. Strain rate, 0.05 in. per in per min.

Alloy Type	Control or Irradiated[a]	Yield Strength, 0.2 per cent Offset, psi	Ultimate Tensile Strength, psi	Reduction of Area, per cent	Uniform Elongation, per cent	Rockwell Hardness, B Scale	ASTM Grain Size
301...........	Control	38 400	98 700	83	56	80	2
	Irradiated	87 000	113 200	81	48	94	
302...........	Control	33 850	95 500	...	...	74	4
	Irradiated	84 000	111 300	...	...	94	
302 B........	Control	33 500	107 800	...	...	78	4
	Irradiated	81 500	125 000	...	...	97	
304 ELC......	Control	24 350	86 300	74	63	60	4
	Irradiated	75 500	103 800	73	58	86	
305...........	Control	32 100	98 000	...	...	67	5
	Irradiated	71 400	103 600	...	...	92	
321...........	Control	31 200	84 800	...	...	74	7
	Irradiated	90 600	105 800	...	...	94	
347	Control	37 000	97 600	71	49	81	8
	Irradiated	96 500	114 800	62	25	99	

[a] All the irradiated specimens received an integrated flux of 3.9×10^{19} nvt with the exception of the types 304 ELC and 321 stainless steels which received 7.8×10^{19} nvt.

The times given for the performance of specific tests are realistic but do not include time for set-up of apparatus, development of the apparatus, down time for service, and time required to get out of difficulties such as retrieving a broken radioactive specimen from the recesses of a Templin grip. Apparatus is being continually improved, and in-cell testing at speeds approaching those achieved in a normal laboratory is not far off.

Austenitic Stainless Steels

Experimental Data:

The data from hardness and tension tests on a series of austenitic stainless steels are shown in Table I. All steels were initially in the annealed condition and the irradiated specimens were subjected to temperatures no higher than 200 F during irradiation. All the steels were irradiated simultaneously and received the same integrated fast neutron flux (3.9×10^{19} nvt), with the exception of the types 304 ELC (extra low carbon) and 321 stainless steels; these received twice the integrated fast neutron flux (7.8×10^{19} nvt) received by the other steels. Although the yield stress is affected by irradiation to a greater extent than the other properties listed in Table I, it is apparent in Fig. 1 that the yield stress changes only slightly between these two integrated fluxes. Therefore, for comparison purposes, the integrated flux for all the steels in Table I may be assumed to be about the same.

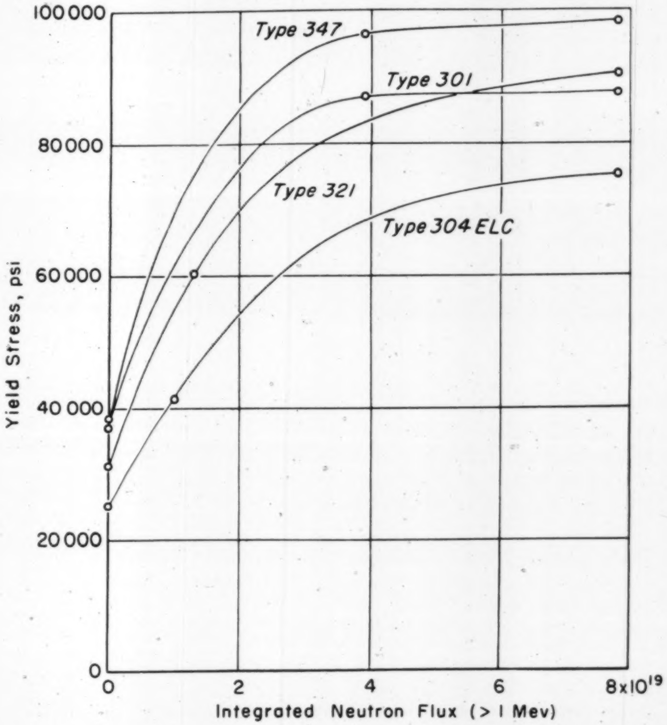

FIG. 1.—Effect of Integrated Fast Neutron Flux on the Yield Strength (0.2 per cent Offset) for Types 301, 304 ELC, 321, and 347 Austenitic Stainless Steels Irradiated Below 200 F.

The irradiations increased the hardnesses about 20 points on the Rockwell B scale, raised the yield stresses by a factor of 2 or 3, and increased the ultimate strengths from 5 to 20 per cent. The only large change in ductility was the decrease from 49 to 25 per cent in the uniform elongation of the type 347 stainless steel. Results on similar materials, reported by Leeser and Sutton (2), agree fairly well with these data.

The distinguishing feature of these irradiated metals is not the increased strengths but is the behavior during test. The stress-strain curves of the irradiated metals are distinctly different in shape from curves for the unirradiated metals.

Figure 2 shows the conventional stress-strain curves of the irradiated and unirradiated, annealed, type 347 stainless steel. Curve *A*, showing the behavior of the unirradiated metal, is of the usual shape. The slope of the curve decreases continuously from the onset of plastic deformation to the maximum load.

The shape of the curve is not strain rate dependent over small ranges of strain rate. Changing the strain rate by a factor of five (from 0.01 to 0.05 in. per in. per min) does not change the curve by any measurable amount. Curve *B* is for the irradiated steel pulled at a rate of 0.01 in. per in. per min. The curve is marked by points of inflection that do not occur in the unirradiated metal. Curve *C* is for the irradiated steel pulled at a rate of 0.05 in. per in. per min; this curve, shown in detail in the insert in Fig. 2, goes through a maximum at a plastic strain of about 0.004 (elongation of 0.7 per cent), falls, and then rises

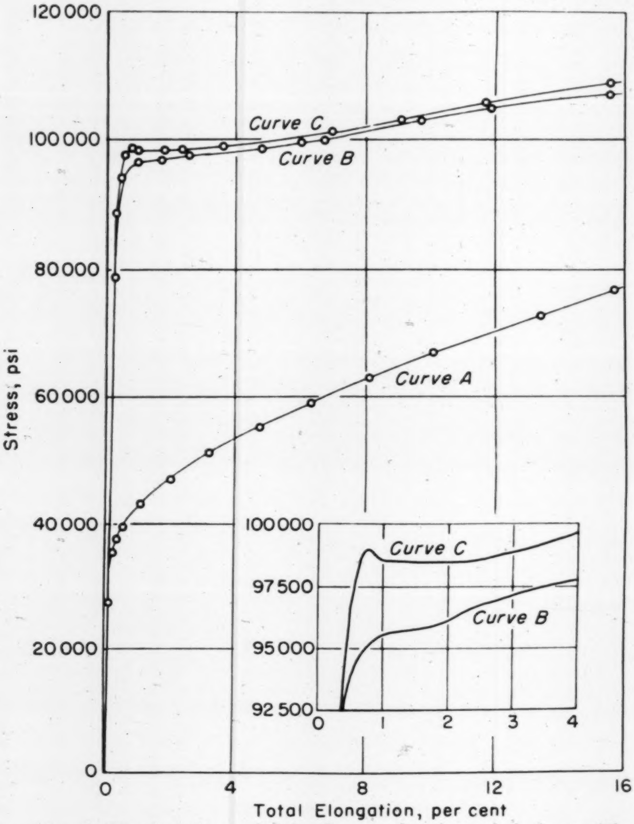

FIG. 2.—Conventional, Tension Stress-Strain Curves for Annealed Austenitic Stainless Steel Type 347

Curve A.—Composite curve from two tests on unirradiated metal at strain rates of 0.01 and 0.05 in. per in. per min.

Curve B.—Irradiated (7.8 × 10^{19} nvt); strain rate 0.01 in. per in. per min. Note region of low work hardening.

Curve C.—Irradiated (7.8 × 10^{19} nvt); strain rate 0.05 in. per in. per min. Note "yield point" and yield point elongation.

again to the maximum load. Of the steels listed in Table I, only the types 304 ELC and 347 stainless steels showed these yield points, at a strain rate of 0.05 in. per in. per min. The decreases in stress of the types 304 ELC and 347 stainless steels at the "yield point" were 600 and 800 psi, respectively. All the steels did, however, show in varying degree the same general type of stress-strain curve as is shown by curve *B*, Fig. 2.

To test the strain rate dependence of the yield stress, a series of type 304 ELC stainless steel specimens was irradiated in the LITR to an integrated fast flux of 7 × 10^{18} nvt. This was approximately one-tenth the dose received by the samples for which curves are shown in Fig. 2. These specimens were tested over a 40 to 1 range of strain rates. The results, shown in Fig. 3, indicate that the yield stress of the irradiated steel is strongly dependent on strain rate over this range. All stress strain curves for the irradiated specimens were again of the same general form as curve *B* in Fig. 2, except that the irradiated specimen tested at a strain rate of 2 in per in. per min showed a "yield point" with an immeasurably small drop in load. The unirradiated specimens showed no unusual behavior or strong strain rate dependence.

Subsize Izod specimens of irradiated and unirradiated austenitic stainless steels were tested at −320 F. All the unirradiated specimens bent sufficiently to permit the striker of the impact machine to pass, but no cracks were initiated at the root of the notches. All the irradiated specimens cracked in the same test, although no complete fractures occurred. After fracture began, the specimens bent sufficiently to permit the striker to pass. The fracture in all the irradiated specimens propagated at least half-way across the specimen.

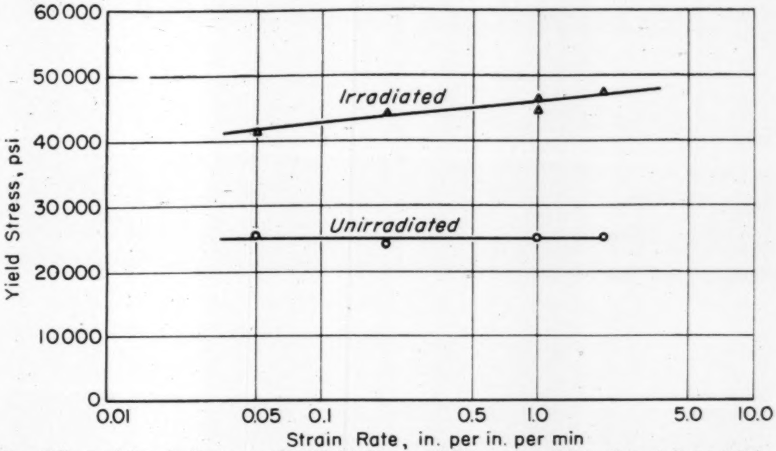

FIG. 3.—Effect of Strain Rate on the Yield Stress of Control and Irradiated (1 × 10^{19} nvt) Tension Specimens of Annealed Type 304 L Stainless Steel.

Discussion:

The yielding phenomenon observed is not new in irradiated, face-centered cubic metals; Blewitt observed similar behavior in irradiated high-purity copper single crystals several years ago (**21**). In fact, strain aging in austenitic steels, with marked yield point on reloading, has been observed at this laboratory (**22**), although no references to the subject have been found in the literature. The yield point is probably not important *per se* but it did lead to the reported (Fig. 3) series of tests in which the strong strain-rate dependence of the yield stress was found. It is believed that this strain rate effect may be of technological importance; at the very least, it will require the use of a definite value of strain rate for all tests of irradiated metals if the results are to be comparable.

TABLE II.—MECHANICAL PROPERTIES OF AN IRRADIATED ASTM SPECIFICATION A 212 GRADE B CARBON-SILICON STEEL.

ASTM grain size No. 5; normalized from 1900 F; irradiation temperature less than 200 F.

Integrated Neutron Flux	Strain Rate, in. per in. per min	Yield Stress, psi	Ultimate Tensile Strength, psi	Reduction of Area, per cent	Uniform Elongation, per cent
0	0.05	51 400	75 100	62	19
0	0.05	47 300	75 000	64	23
0	0.05	51 600	76 100	67	24
10^{19} nvt	0.05	65 400	80 800	68	18
10^{20} nvt	0.05	94 900	97 100	28	5.4
10^{20} nvt	0.05	92 600	97 000	24	4.6
0	0.5	50 700	76 700	64	23.2
0	0.5	52 600	78 800	58	20.2
10^{20} nvt	0.5	98 500	100 100	32	4.5
10^{20} nvt	0.5	94 500	97 800	35	12

TABLE III.—COMPOSITION OF CARBON STEELS, PER CENT BY WEIGHT.

Item	Carbon	Manganese	Phosphorus	Sulfur	Silicon	Aluminum	ASTM Grain Size
A 106	0.24	0.72	0.018	0.023	0.20	...	No. 2
A 106 Fine Grain	0.24	0.70	0.019	0.020	0.19	Fine Grain	No. 7
A 212B	0.24	0.81	0.020	0.040	0.248	...	No. 5

The effect of speed of deformation on the irradiated austenitic steels suggests that the manner of initiation of a fracture in these materials is of some concern. It is believed significant that the crude impact test used was capable of initiating fracture in the irradiated specimens when only bending resulted in testing the control specimens in a similar manner. It does not seem unreasonable to suspect that irradiation made fracture possible by raising the yield stress, at the relatively high testing speeds employed, above the fracture stress of the metal.

The yielding phenomenon occurred only in the types 347 and 304 ELC alloys; both were of low carbon content (0.05 and 0.03 per cent respectively). It is unlikely that the carbon content of the other alloys is this low. It appears, then, that the yield phenomenon is most apparent in alloys of very low carbon content.

That irradiation lowered the reduction of area and uniform elongation but little is reassuring, but this should be confirmed over a wide range of testing speeds before this behavior can be considered typical. As Form and Baldwin (**24**) have recently shown, ductility is dependent in a rather complex manner on both strain rate and temperature in stainless steels. Crude measurements showed that the total elongation of the specimens of type 304 ELC stainless steel pulled in tension over a 40:1 range of strain rates (see Fig. 3) did not vary by more than 10 per cent.

All the austenitic stainless steels tested were irradiated at less than 200 F. This is unrealistic if the data are to be applied to the design of power reactors because annealing may take place at the operating temperature. Future irradiations should be carried out at high temperatures, and more than the time-temperature-neutron flux relationships should be sought. The effects of radiation on metallurgical changes are not yet well understood, but significantly, in the aging of copper-beryllium alloys (6) and the ordering of disordered superlattices (3), radiation seems to act roughly in the same manner as an increase in temperature. That is, in the presence of radiation, diffusion-dependent metallurgical reactions take place at certain temperatures at rates that would require higher temperatures in the absence of radiation.

Until tests show otherwise, a stainless steel to go into service at a given temperature in intense neutron fluxes should be suspect if time and temperature at perhaps 100 or 200 F higher are known to give rise to metallurgical changes in a manner that reduces any desirable property of the metal. The recent study of irradiation-accelerated ferrite formation in type 347 stainless steels illustrates the possibilities (12).

CARBON STEELS

Experimental Data:

Tension test results for a carbon steel meeting ASTM Specification A 212[4] Grade B are given in Table II. Chemical analysis of the metal is given in Table III, and all specimens were normalized from 1900 F before irradiation or test. Irradiation in the LITR at 140 F to an integrated flux of 10^{19} nvt caused about a 30 per cent increase in the yield stress; irradiation in the MTR (dose, 10^{20} nvt) nearly doubled the unirradiated yield stress. Moderate increases in tensile strength, 7 and 25 per cent in the LITR and MTR respectively, were noted. The decrease in ductility, as measured by the reduction of area and uniform elongation, is much more marked than in the austenitic stainless steels.

A tenfold increase in the strain rate in the tension test (from the normal rate of 0.05 to 0.5 in. per in. per min) has little effect on the yield or ultimate tensile strength of either irradiated or unirradiated steel (see Table II). Although there is some spread in the data, it appears that the reduction of area in the irradiated steels is greater for the steel pulled at the higher rate. The spread in the uniform elongation values is too great for any conclusions to be drawn.

As was discussed in the section on theory, exposure of a metal to elevated temperatures either during or after irradiation may anneal out the irradiation-produced defects that change the mechanical properties. The yield stress of specimens of the A 212 Grade B steel irradiated at 570 F in the LITR to an integrated flux of 10^{19} nvt was increased from 50,000 to 56,800 psi; the yield stress of a specimen exposed to the same neutron flux at 140 F during irradiation was 65,400 psi (Table II). Thus it can be seen that appreciable annealing of the lattice defects that cause increased yield stress has taken place during irradiation at 570 F.

Irradiation at 570 F, however, raised the ultimate tensile strength from about 75,000 psi to 83,900 psi; irradiation at 140 F raised the ultimate strength to only 80,800 psi, although the lower temperature of irradiation resulted in a higher yield stress. Also it was observed that the reduction of area (57 per cent) and uniform elongation (12 per cent) of the specimens irradiated at 570 F were lower than for the specimen irradiated at 140 F (Table II). Until further tests, now in progress, can be completed, no great importance is attached to the numerical values (except the yield strength) obtained from comparative irradiations at 140 and 570 F. Instead, the importance of these data, comparing mechanical property changes at high and low irradiation temperatures, is that they show that annealing at a given temperature of the irradiation effects responsible for the changes in one mechanical property may take place more or less independently when compared to another mechanical property. Here, although a close correlation between yield and ultimate strength would not be unexpected, it is seen that a 570 F irradiation raised the yield stress less than at a lower irradiation temperature but raised the ultimate tensile strength more than at the lower irradiation temperature. Until the phenomena are well understood it is imperative to measure all mechanical test properties individually (at each condition of flux and irradiation temperature) rather than rely on a correlation that experience may have taught to be justified in experiments on unirradiated metals.

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[4] Tentative Specification for High Tensile Strength Carbon-Silicon Steel Plates for Boilers and Other Pressure Vessels (A 212 - 54aT), 1955 Book of ASTM Standards, Part 1, p. 501.

Three of the four tension specimens irradiated to 10^{20} nvt showed no evidence of a yield point; the fourth specimen showed a scarcely visible yield point. Neither of the specimens exposed to 10^{19} nvt showed a yield point. All control specimens of this steel, of course, showed distinct yield points. The general characteristics of the irradiated carbon steel specimens at the onset of plastic deformation are: the rather abrupt start of plastic deformation (high proportional limit) with an almost vanishingly small rate of work hardening; at an elongation of 1 or 2 per cent there follows an increase in the rate of work hardening that soon starts to decrease up to the maximum load. Curve *B* in Fig. 2 for stainless steel illustrates very well the general characteristics of the conventional stress-strain curve for the irradiated A 212 Grade B carbon steels.

The results of notch-impact tests on subsize Izod specimens for the A 212 Grade B steel, irradiated at the same time as the tension specimens, are shown in Figs. 4 and 5. The energy-test temperature relationships are shown in Fig. 4, and the contraction below the root of the notch is plotted against test temperature in Fig. 5. These latter curves were made because it was hoped that some indication of the distinction between fracture and ductility transition temperatures could be obtained and because some of the specimens did not fracture completely.

In Fig. 4 it may be seen that a dose of 10^{19} nvt (in the LITR) is sufficient to raise slightly the transition temperature of the steel, but perhaps more important is the observation that the energy required for fracture below the transition temperature is relatively constant up to the transition temperature. In the control specimens, the energy curve below the transition temperature is not flat. The metal irradiated in the MTR (dose, 10^{20} nvt) exhibited distinctly brittle behavior up to about 122 F; not only is the energy for fracture markedly less below the transition temperature than the two other curves, but even above the transition temperature the energy for fracture is only about one half that required to break the control specimens.

The curve for the control specimens in Fig. 5, derived from measurements of the contraction below the root of the notch, appears to show evidence of the

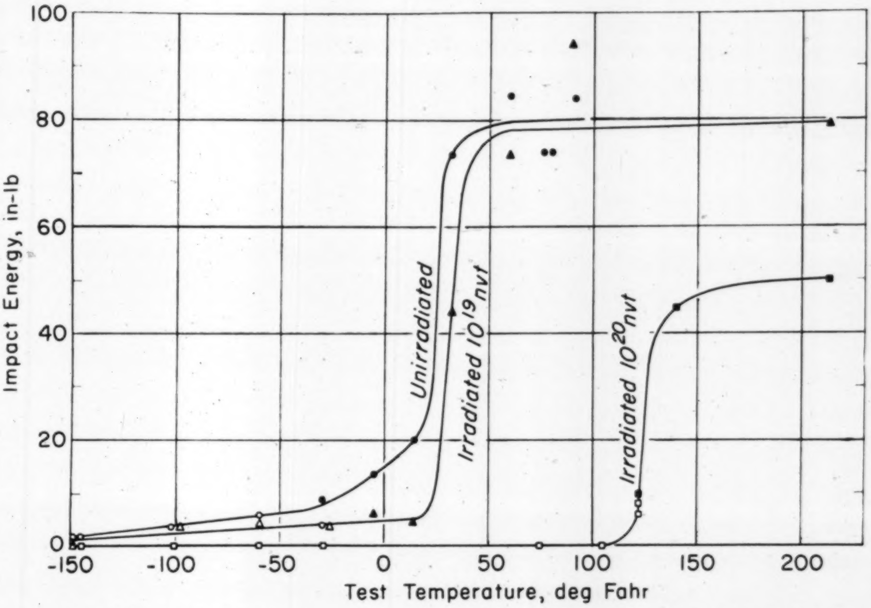

FIG. 4.—Effect of Irradiation on Impact Energy Curve of A-212B Carbon-Silicon Steel.

Normalized from 1900 F. Irradiation temperature, 195 F max. Solid points, incomplete fracture. Open points, complete fracture.

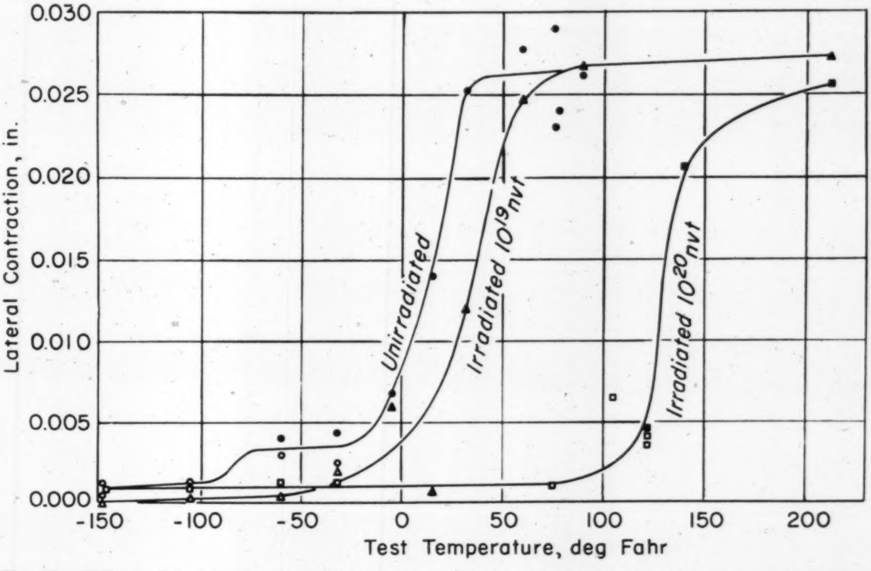

FIG. 5.—Effect of Irradiation on Lateral Contraction in the Notch Impact Test of A-212B Carbon-Silicon Steel.

Normalized from 1900 F. Irradiation temperature, 195 F max. Solid points, incomplete fracture. Open points, complete fracture.

ductility transition temperature below about −60 F. Any evidence of a ductility transition in the LITR specimens that received a dosage of 10^{19} nvt could well be hidden by the wide scatter. The MTR irradiated specimen metal has only one point that suggests that a ductility transition can be resolved. The contractions for the control and irradiated specimens are almost the same at the highest test temperature; in the energy-temperature curves, Fig. 4, the spread between the curves at the highest test temperature was much greater.

Irradiation definitely increased the fracture transition temperature of the irradiated steel; there is also evidence to suggest that the ductility transition has been lost or moved up to the same temperatures as the fracture transition temperature. Also it will be noted that the shift in transition temperature is much more integrated flux sensitive, at higher integrated fluxes, than any of the other properties measured for this steel. In Fig. 6, the various mechanical properties of the steel are plotted against integrated flux. Although the data are scanty, it is readily apparent that the transition temperature is much more greatly flux dependent than even the elongation or the reduction of area. The transition temperature appears to increase almost linearly with increasing integrated flux; the yield stress and the ultimate tensile strength are much less flux sensitive and the curves of these values plotted against integrated flux indicate that the curve is asymptotic.

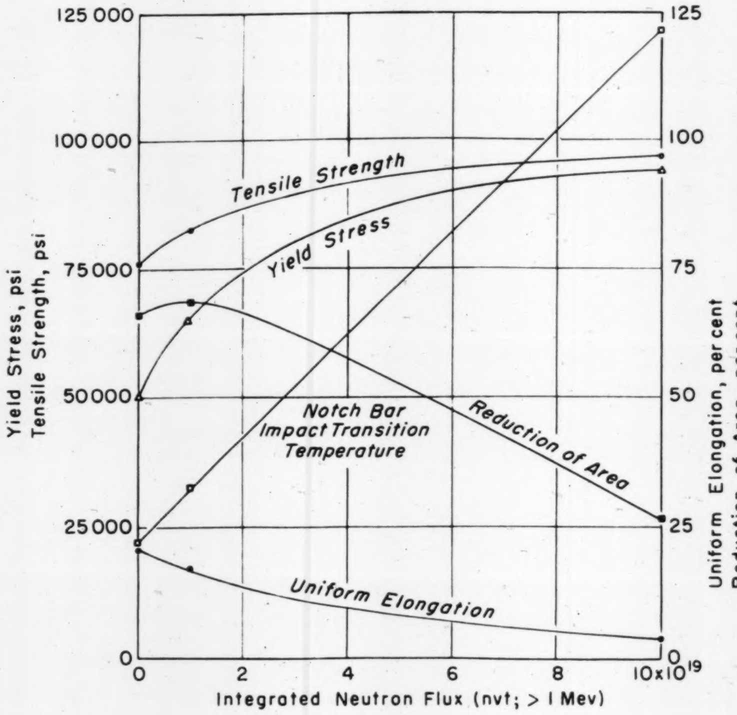

FIG. 6.—Integrated Fast Neutron Flux Dependence of Several Mechanical Properties of A-212B Carbon-Silicon Steel.

In a preliminary attempt to determine the effect of grain size on the irradiation effects, two laboratory experimental heats of ASTM Specifications A 106[5] steel that had been formed into pipe in the production mill were made available by the Jones & Laughlin Steel Corp. Research Dept. As may be seen from Table III, the analyses are almost identical except that one heat was aluminum killed to secure a small grain size. Irradiations of impact and tension specimens were made in the LITR at about 140 F and at 570 F. The specimens irradiated at 140 F received a dose of 10^{19} nvt but, because of space limitations in the furnace in the reactor, the fine-grain tension specimen irradiated at 570 F received a dose of only about 5×10^{18} nvt and the coarse grain specimen irradiated at 570 F perhaps half this much. The difference in the notch impact properties was within the scatter of the control specimens, and accordingly the data are not reproduced here. Table IV shows the results of the tension tests. Again, as for the A 212 Grade B steel, annealing effects are clearly seen; the yield stress is less for the specimens irradiated at the higher temperature. The specimens of both fine and coarse grain A 106 steel irradiated at 140 F have roughly the same increases in yield stress. In view of the variation in integrated flux, the relative effects of annealing on the yield stress of the two steels irradiated at 570 F cannot be determined. The behavior of the ultimate tensile strength tends to confirm the observation, made on the A 212 Grade B steel, that an elevated temperature during irradiation may, by annealing, significantly affect the yield stress but have less effect on the ultimate tensile strength. The reduction of area and uniform elongation measurements showed no significant change.

TABLE IV.—MECHANICAL PROPERTIES OF TWO IRRADIATED A 106 CARBON STEELS.

Strain rate 0.05 in. per in. per min; normalized from 1700 F.

Integrated Neutron Flux	Irradiation Temperature, deg Fahr.	Yield Stress, psi	Tensile Strength, psi	Reduction of Area, per cent	Uniform Elongation, per cent
A 106 Fine Grain Steel ASTM Grain Size No. 7					
0	...	57 700	75 400	67	18.8
1×10^{19} nvt	140	72 600	78 400	70	23.2
5×10^{18} nvt	570	62 500	78 100	69	20.2
A 106 Coarse Grain Steel ASTM Grain Size No. 2					
0	...	50 400	85 000	67	20.2
1×10^{19} nvt	140	71 600	89 500	68	16.0
2×10^{18} nvt	570	53 900	86 400	68	17.7

Discussion:

The general effects of irradiation appear to be: a sharp increase in the yield stress, elimination or modification of the yield point, sharply reduced uniform elongation and reduction of area, and an elevation of the transition temperature in the impact test with lowering of the energy requirements for ductile fracture.

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[5] Tentative Specification for Seamless Carbon-Steel Pipe for High-Temperature Service (A 106 - 55 T), 1955 Book of ASTM Standards, Part 1, p. 36.

It also appears, with less certainty, that what has been assumed to be the ductility transition is moved to higher temperatures, eventually to merge with the fracture transition or be obscured by it.

The yielding behavior of the irradiated carbon steels seems to parallel that of the irradiated stainless steels. At the moment, the changes in the yield point behavior seem rather arbitrary, and the issue is further clouded when it is noted that Kunz and Holden observed (13) that in high-purity iron single crystals, no yield point was observed, although there appears to have been a fairly strong strain rate dependence of the yield stress; but irradiation (10^{18} nvt, neutron energy unspecified) raised the yield stress by a factor of about 2 and apparently (Fig. 5 of their paper) caused a yield point to occur. Also Kunz and Holden noted that the elongation at fracture was greater in the irradiated crystals. In a single test of a polycrystalline specimen of a high-purity iron (dose, 10^{19} nvt), we observed that the behavior at yielding was similar to curve *B* in Fig. 1 for the austenitic stainless steels, although the stress-strain curve for the unirradiated specimen showed no points of inflection. The specimens used had been quenched from a subcritical anneal.

From this somewhat confusing mass of data it appears that the yielding phenomena in iron-carbon alloys are rather more complicated than those observed in the austenitic stainless steels, and that the analysis of the carbon steels may strongly affect the yielding behavior.

The ductility decrease engendered by irradiation appears to be of possible serious magnitude. Although annealing may take place at reasonable temperatures, the ultimate tensile strength does not seem to anneal in a manner that parallels the yield strength. Large increases in the transition temperature should certainly cause concern in reactors in which carbon steels may receive high integrated flux doses. However, we do not know that the observed increase in the transition temperature is really bad: the steels tested seemed to behave in a manner distinctly different from unirradiated metal. So, until objective experiments are designed to ferret out the truth, one cannot unequivocally say that the elevated transition temperature would disqualify a steel for service, because there is no assurance that past experience is a reliable guide to judge irradiated metals.

The observation, best understood by inspection of Fig. 6, that tensile strength, yield strength, elongation, reduction of area and transition temperature are not integrated flux dependent in even roughly parallel fashion serves to warn the experimenter and the designer, who must eventually use the data, that elucidation of the problem of strength and ductility in irradiated carbon steels will require more than a superficial test program for its understanding. The effects of temperature, superimposed on flux dependence, appear to be different for the various mechanical properties. The ultimate tensile strength in particular seems to be much less affected by annealing during irradiation than does the yield strength.

We believe the above points out clearly that: (1) irradiations to secure data for a given combination of temperatures, fluxes, and times must be performed at the anticipated service conditions and (2) our ignorance of the real meaning of our mechanical tests in terms of service behavior, even for unirradiated metals, is going to increase immeasureably the difficulty of finding out what these relationships are for irradiated metals. The task of setting up materials specifications for metals to be subjected to neutron irradiation in service will be a difficult but interesting task.

CONCLUSIONS

Over the range of integrated neutron fluxes from 10^{19} to 10^{20} nvt, for the steels tested, the following conclusions seem justified:

1. The behavior of carbon and stainless steels in the tension and impact tests is markedly altered by irradiation.

2. Previous observations that neutron irradiation may increase the hardness, yield strength and tensile strength while only moderately decreasing the ductility in the tension test of austenitic stainless steels have been confirmed.

3. The stress-strain curves of irradiated austenitic stainless steels are unusual in that the rate of work hardening is abnormally low up to a few per cent elongation at which point the work hardening rate increases abruptly then decreases continuously until necking begins.

4. Yield points have been observed in irradiated austenitic stainless steels, but the similarity or dissimilarity to yield phenomena in carbon steels has not been determined.

5. The yield stress of irradiated austenitic stainless steels has been shown to be strongly dependent on strain rate; the yield stress increases with strain rate.

6. The tendency of an annealed austenitic stainless steel to show a yield point after irradiation appears to be inversely proportional to carbon content.

7. Subsize Izod specimens of irradiated austenitic stainless steels will fracture at least half way across the specimen under the same test conditions that will cause only bending with no cracking in the unirradiated metal.

8. Strain aging in austenitic stainless steels may give rise to a yield point on subsequent tension testing.

9. Previous reports of increased tensile and yield stress in normalized, irradiated, low-carbon steels have been confirmed.

10. Reduction of area and uniform elongation of normalized, low-carbon steels is decreased by neutron irradiation of 10^{20} nvt much more drastically than in austenitic stainless steels.

11. Irradiation tends to eliminate the yield point in normalized low-carbon steels, although the stress-strain curve may show a region of low work hardening for elongations of several per cent.

12. Irradiation at 570 F decreases the extent of the radiation induced elevation of the yield stress, although the ultimate tensile strength may be simultaneously increased more than if irradiated at lower temperatures.

13. The ductile brittle transition temperature of normalized A 212 Grade B steel is elevated by neutron irradiation at a rate that appears nearly linear with integrated neutron flux.

14. Marked increases in yield strength may be observed at lower integrated flux levels than are elevations in the ductile brittle transition temperature.

15. The level of the energy - test temperature curve for the irradiated carbon steels is depressed below the curve for the unirradiated, at all temperatures of test (-320 F to 212 F).

16. At the highest test temperature employed (212 F), irradiated and control specimens of the carbon steels show approximately the same contraction at the root of the notch of the Izod specimen, although the energy required for (incomplete) fracture of the irradiated specimen was only about one half that required for the control specimens.

SUMMARY

The primary purpose of this paper has been to show that irradiated carbon and stainless steels behave in an entirely different manner in mechanical tests than do unirradiated alloys. These differences in behavior are believed important because they imply that the response of an irradiated metal will not be the same as an unirradiated metal to the same conditions of stress, strain, time and temperature in service. Furthermore, it has been demonstrated that temperature of irradiation, or simulated service temperature, does not affect all mechanical properties in the same way.

Also it should be re-emphasized that the data in this paper were obtained at relatively low levels of integrated neutron flux. If metals in future power reactors are exposed to integrated fluxes of 10^{22} or 10^{23} nvt, that is 100 to 1000 times greater than that to which the specimens used here were subjected, effects that were not seen at 10^{20} nvt may be very important. Transmutation effects, certainly, and metallurgical change effects, possibly, will be of importance in many alloys after long, high flux irradiations.

The study of radiation effects in metals has been going on less than 10 yr. In view of the short time, the difficulties of experimentation, and the small number of workers, it should be emphasized that we probably know very little about radiation effects in metals and that what has appeared in the literature represents a very small part of the information that will be required when the ASTM writes its first specification on "Steels for Service in Nuclear Reactors."

Acknowledgment:

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DISCUSSION

MR. J. R. KATTUS.[1]—Do the authors have any information to show whether the different flux intensities produce different effects on metals after exposures to equal integrated fluxes?

MR. J. C. WILSON (*author*).—We do not have any direct information on this, but we would expect that there would be a difference, especially in the case where annealing would take place.

What Mr. Kattus asks is this: Suppose you reach the same value of integrated flux in two different specimens, in one by irradiation in a low neutron flux for a long time, in the other by irradiating in a high flux for a correspondingly shorter period of time; will the specimens behave the same?

Since the annealing of defects would probably be a function of temperature and since the creation of defects proceeds at two different rates, we would expect that the annealing behavior would be different. We do not have direct data on this at the moment. I think it exists for other materials but is not directly applicable to metals.

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[1] Head, Metallurgy Department, Southern Research Institute, Birmingham, Ala.

EFFECT OF TIME AND TEMPERATURE ON IMPACT AND TENSILE PROPERTIES OF HOT-ROLLED LOW-CARBON STEELS DURING STRAIN-AGING*

By F. Garofalo,[1] G. V. Smith,[2] and D. C. Marsden[3]

Synopsis

The influence of time and temperature on notch-impact and tensile properties during strain-aging has been determined for three commercial grades of hot-rolled, low-carbon steel. Notch-impact tests were made over the transition-temperature range on the steels as hot-rolled and after straining 10 per cent in tension and aging at 75 F. Notch-impact tests were also made on material strained and fully aged at 75 F and exposed for various time intervals at 450, 900, 1200, and 1650 F. Tension tests at room temperature after many of these treatments were also made.

Upon straining and aging at 75 F, or exposing strained and fully aged material at 450 F, a pronounced shift in the notch-impact transition-temperature range to higher temperatures is found. The maximum shift upon aging at 75 F is essentially the same for a silicon-aluminum killed steel made by liquid metal practice, a capped open-hearth steel, and a capped bessemer steel. An additional shift in the transition range is found for the bessemer steel upon aging at 450 F after fully aging at 75 F, but essentially no additional shift is found for the other two steels. After straining and aging at 75 F or 450 F for several years, the impact results do not show an over-aging effect, that is, any tendency to return to the original properties. Exposure at 900 or 1200 F after straining and fully aging at 75 F brings about a slight improvement in the notch-impact properties but no return to the original properties. Normalizing at 1650 F eliminates all strain and strain-aging effects on notch-impact transition-temperature range.

After straining and aging at 75 F for several years, no appreciable recovery in yield or tensile strength was observed. Some recovery in both was found at 450 F, but a great deal more was found at 900 and 1200 F. The degree of recovery in yield and tensile strengths differed in each case.

Various observations in the past have shown that steels, which under normal test conditions are ductile, may exhibit reduced ductility under certain service conditions. One of the several factors that has been investigated extensively, and which is known to decrease ductility, is strain-aging (**1-8**).[4] The effect of strain-aging in decreasing toughness is especially evident when toughness is measured in terms of the transition-temperature range in a notch-bend or notch-impact test. In service failures,

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[4] The boldface numbers in parentheses refer to the list of references appended to this paper, see p. 718.

the plastic strain, which conditions the metal for strain-aging, may occur during fabrication or during service as a result of stress concentrations or overloading.

Depending on the steel being tested and the property measured (**8, 10**), strain-aging effects in low-carbon steels predominate in the temperature range between 500 F and subatmospheric. Above 500 F other effects, such as crystal recovery, carbide spheroidization and possibly recrystallization predominate and mask the true strain-induced effects of strain-aging. The effect of time and temperature beyond 500 F should be investigated, however, to determine the usefulness of interim stress-relief treatments for eliminating strain and strain-aging effects on toughness.

The present investigation was undertaken to determine the influence of time on notch-impact and tensile properties after prestraining 10 per cent in tension and aging at 75 F for various time intervals and to determine the influence of time and temperature upon these properties after exposing at higher temperatures material that was strained and fully aged at 75 F. Notch-impact tests over the transition-temperature range and tension tests at 75 F were made on three commercial low-carbon steels in the hot-rolled condition,[5] after straining and aging at 75 F, and after straining and fully aging at 75 F and exposing at 450, 900, 1200, and 1650 F.

Materials and Procedures

The three steels investigated are described in Table I, which includes for each steel the identification, type, chemical composition, and grain size in the hot-rolled condition and after normalizing. Steel A was made by liquid metal practice and deoxidized with silicon and aluminum as indicated in Table I. Steels B and C are, respectively, capped open-hearth and bessemer steels and are not deoxidized.

TABLE I—DESCRIPTION OF STEELS.

Steel	Melting Practice	Chemical Composition, per cent							Hot Rolled		Normalized	
		Carbon	Manganese	Phosphorus	Sulfur	Silicon	Aluminum[a]	Nitrogen[a]	Grains per sq mm[b]	ASTM Grain Size	Grains per sq mm[b]	ASTM Grain Size
A.....	Liquid metal—deoxidized with silicon and aluminum	0.25	0.56	0.017	0.028	0.13	0.013	0.011	4850	No. 9	7500	No. 9–10
B.....	Capped open-hearth	0.07	0.43	0.006	0.026	0.007	0.005	0.005	1050	No. 7	3450	No. 8–9
C.....	Capped bessemer	0.08	0.47	0.075	0.032	0.012	0.006	0.016	750	No. 6–7	2950	No. 8–9

[a] Acid Soluble.

[b] Pearlite colonies were omitted.

Steel A was received in the form of seamless pipe with a wall thickness of 0.337 in, and an outside diameter of 4.5 in. Steels B and C were in the form of butt-welded pipe of 0.300 in. wall thickness and 3.0 in. outside diameter.

Prestraining and Aging of Cold-Worked Steels:

The prestraining operation for each steel was performed on a 12-ft length of pipe which was strained in tension approximately 10 per cent over a 10-ft gage length. Punch marks were placed at 6-in. intervals over the central 10-ft gage section, leaving a 1-ft length at each end for gripping. The elongations computed over each 6-in. length range from 8.2 to 12.3 per cent; however, in obtaining specimen blanks from each cold-worked pipe section, only those regions were used which had been strained between 9.2 and 11.2 per cent. The specimen blanks, cut from the strained pipe, were approximately 2 in. wide and 7 in. long. In sectioning the butt-welded pipes, longitudinal cuts were made approximately 0.5 in. apart on either side of the weld and the 1-in. strip discarded.

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[5] Similar but more comprehensive results on these three steels after normalizing have been reported elsewhere (**8**).

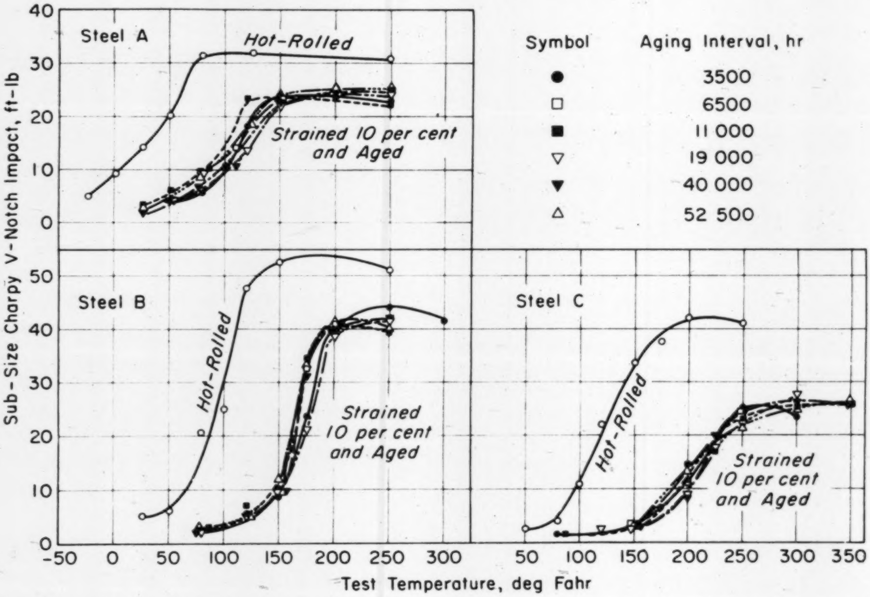

Fig. 1.—Effect of Straining 10 per cent in Tension and Aging at 75 F on Impact Resistance-Temperature Curves.

The specimen blanks removed from the cold-worked pipes were aged at 75 F for various time intervals up to approximately 6 yr. After aging for 3500 hr at 75 F, a number of specimen blanks were aged for various additional time intervals at 450 F. The material that was exposed at 900 and 1200 F or normalized at 1650 F had been aged at 75 F for 11,000 hr.

Impact Tests:

V-notched impact specimens were prepared from hot-rolled or strained-and-aged material with the notch axis normal to the pipe wall. The thickness of the impact specimen in a direction normal to the notch axis was 10 mm, but because of the thin pipe wall the width was only 5 mm.

The notch-impact transition-temperature range was adequately bracketed by testing three specimens at each of six different temperatures. In some cases the transition range from ductile to brittle rupture was covered by testing at five different temperatures, whereas for an intermediate aging time interval a spot check within the transition was

TABLE II.—MAXIMUM INCREASE IN NOTCH-IMPACT TRANSITION TEMPERATURE (10 FT-LB LEVEL) AFTER STRAINING TEN PER CENT IN TENSION AND AGING AT 75 OR 450 F.

Steel	Transition Temperature Before Straining and Aging, deg Fahr	Maximum Transition Temperature After Aging, deg Fahr		Maximum Increase in Transition Temperature After Aging, deg Fahr	
		Aged at 75 F	Aged at 450 F	Aged at 75 F	Aged at 450 F
A.....	+5	+102	+100	97	95
B.....	+66	+152	+157	86	91
C.....	+94	+202	+252	108	158

made by testing at three different temperatures. The triplicate samples were normally held at the test temperature for at least 15 min. From the curves of impact energy absorption *versus* temperature, a transition temperature was chosen arbitrarily at a level of 10 ft-lb.

Tension Tests:

The tension specimens employed were machined with a reduced section 1.88 in. long and 0.125 in. in diameter. In obtaining automatic load-extension records, a Selsyn motor, averaging, 1-in. gage length extensometer was used giving a 40× magnification on the recorder.

At least two specimens, machined from hot-rolled and from strained-and-aged material, were tested at 75 F. In each case, the flow stress at 0.2 per cent nominal strain (yield strength) and the tensile strength were computed from load values obtained from the autographic load-extension record.

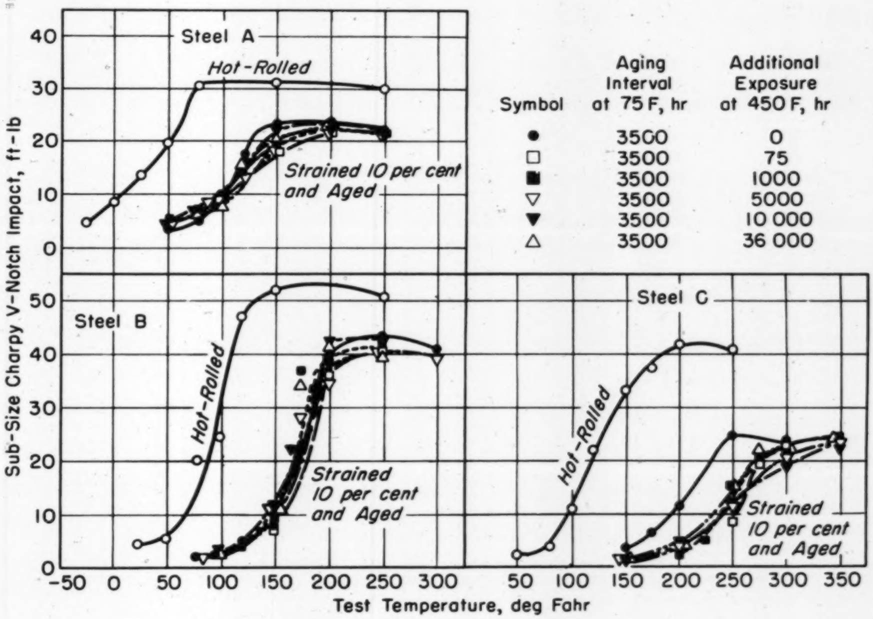

FIG. 2.—Effect of Aging at 450 F on Impact Resistance-Temperature Curves After Straining in Tension and Fully Aging at 75 F.

RESULTS AND DISCUSSION

Effect of Prestraining and Aging on Notch-Impact Transition-Temperature Range:

Impact resistance-temperature curves after hot-rolling and after straining 10 per cent in tension and aging at 75 F are shown in Fig. 1. Each point shown in this and succeeding notch-impact curves represents the average of three values.

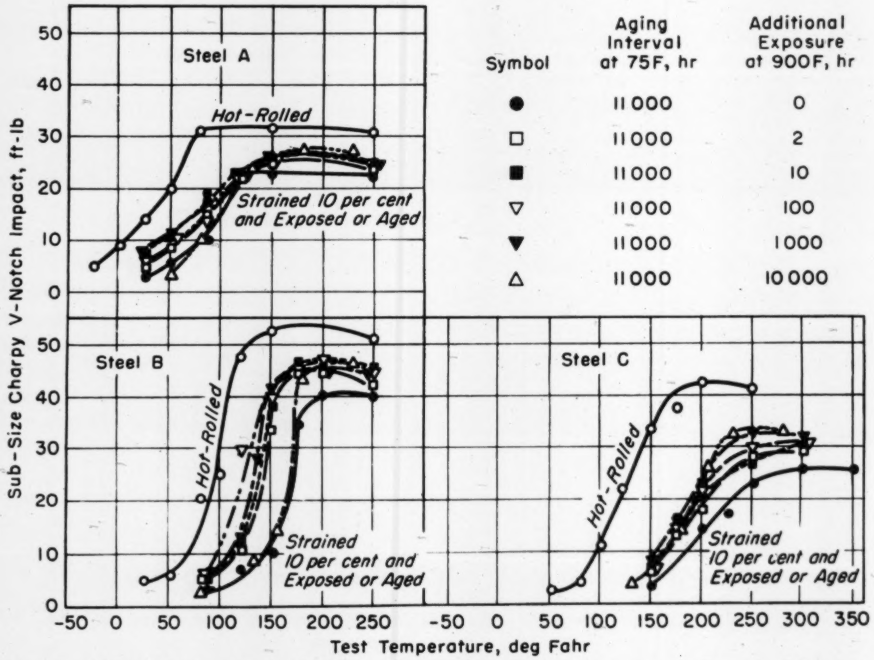

FIG. 3.—Effect of Exposure at 900 F on Impact Resistance-Temperature Curves of Prestrained Steels Fully Aged at 75 F.

As expected, the 10-per-cent prestraining in tension and aging at 75 F shifted the transition-temperature range to higher temperatures. No significant variation is observed, however, in the impact resistance - temperature curves over the range of aging times covered. The fact that the transition-temperature range for each steel after straining and aging is above the aging temperature of 75 F means that a new variable is introduced, that is, a certain amount of aging may have occurred during the holding period at each test temperature. It is not possible to determine readily the absolute effects of this variable. The results in Fig. 1 do indicate, however, that no over-aging tendency, as determined by notch-impact results, exists for these steels during aging at 75 F up to an aging interval of approximately 6 yr.

In comparing the three steels it is found, as shown in Table II, that the maximum shift in transition temperature at a level of 10 ft-lb. upon straining and aging at 75 F is least for steel B, the capped open-hearth steel. The maximum shift for steel A, a silicon-aluminum killed steel with a high total nitrogen content, is somewhat smaller than that for steel C, a capped bessemer steel, but slightly greater than that of steel B.

The effect of aging at 450 F after

fully aging at 75 F on the impact resistance-temperature curve is shown in Fig. 2. The results for steels A and B indicate that following aging at 75 F for 3500 hr, additional aging at 450 F does not bring about an appreciable shift in the transition-temperature range. For steel C, however, a substantial additional shift is found.

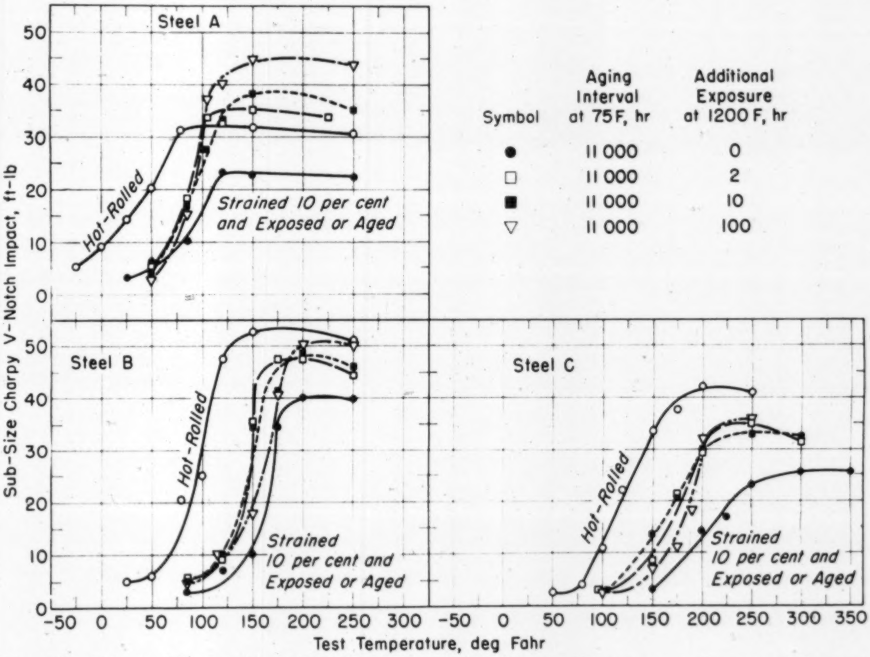

FIG. 4.—Effect of Exposure at 1200 F on Impact Resistance-Temperature Curves of Prestrained Steels Fully Aged at 75 F.

For each of the three steels, the impact resistance - temperature curves show little variation with aging time at 450 F, and, therefore, the results again show lack of over-aging even after an aging interval of more than 4 yr. The maximum shift in the transition temperature chosen at a level of 10 ft-lb. for each steel upon aging at 450 F is also given in Table II. Again it is found that steel B exhibits the least increase, with steel A showing a very slightly greater increase. Steel C shows a much greater shift in the transition temperature.

Effect of Stress-Relief Treatments on Transition-Temperature Range:

The results that have been discussed clearly indicate that extending the aging time at 75 or 450 F to several years does not bring about an over-aging effect resulting in a return to the original notch-impact properties. It is apparent from Fig. 3 that increasing the exposure temperature to 900 F, after straining and aging at 75 F for 11,000 hr, again does not bring about a great deal of improvement in the notch toughness of material fully aged at room temperature.

Steels A and B show some improvement, that is, a shift of the transition-temperature range to lower temperatures for all exposure intervals except 10,000 hr. Steel C shows some improvement for all exposures including 10,000 hr. It is evident from the results in Fig. 3 that an interim stress-relief treatment at 900 F does not eliminate to any great extent the effects of prestraining and aging on notch toughness.

A similar conclusion is reached for various interim stress-relief treatments at 1200 F after prestraining and aging 11,000 hr at 75 F. As shown by the results in Fig. 4, exposure at 1200 F brings about a slight shift of the transition range to lower temperatures; however, the improvement does not seem to be greater in general than that found after exposure at 900 F. The results for steel A show an appreciable improvement with time at 1200 F in notch toughness at temperatures above the transition-temperature range. Less pronounced improvement, independent of time, is found in steels B and C. For all conditions encountered in this investigation, it is found from a comparison of the data in Figs. 1 to 4 and in Fig. 6 that the notch-impact resistance of each steel at temperatures above the transition range seems to be related to the yield strength—the lower the yield strength at room temperature, the greater the maximum notch-impact resistance above the transition range.

As shown in Fig. 5 and by others (7), normalizing by heating at 1650 F for $\frac{1}{2}$ hr and cooling in air completely removes the effects of prestraining and aging at 75 F on the notch-impact resistance - temperature curve. These results show that the impact results for material that was normalized after initially straining and aging 11,000 hr at 75 F are in good agreement with those of normalized material that was not subjected to a prior straining and aging cycle.

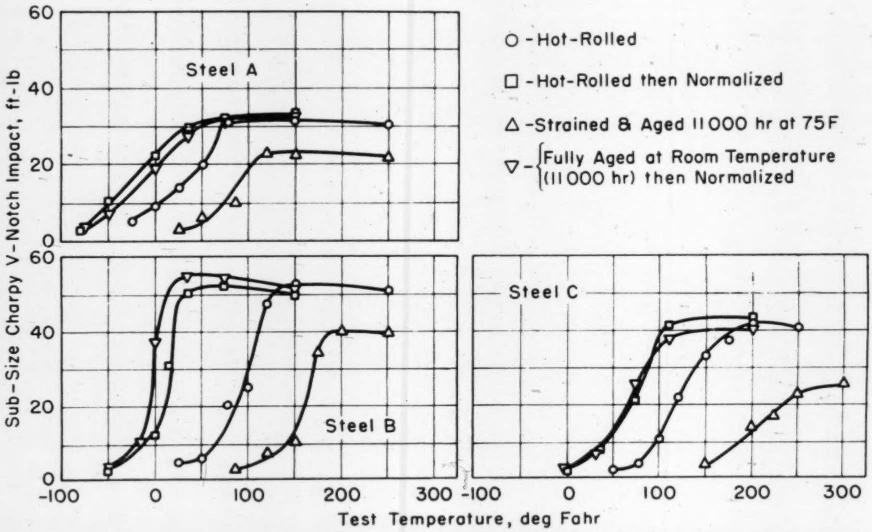

FIG. 5.—Impact Resistance-Temperature Curves of Test Steels in the Hot-Rolled and Normalized Conditions, After Straining Ten per cent in Tension and Fully Aging at 75 F and After Normalizing Fully Aged Material.

Although it is not known at present which structural rearrangements during normalizing remove straining and aging effects, it is known that certain structural changes during heat treatment have a pronounced effect on the transition-temperature range. One such structural change is in ferrite grain size. It is generally accepted that as the average size of the ferrite grains is decreased, the transition-temperature range is shifted to lower temperatures. In the present investigation, it was found, as shown in Table I, that normalizing refined the grain structure of the hot-rolled material. Thus, the lowering of the transition-temperature range upon normalizing is believed to be related primarily to this grain refinement. Other factors, however, such as a change in pearlite spacing, size and distribution of pearlite patches, or amount of aluminum nitride may also be important.

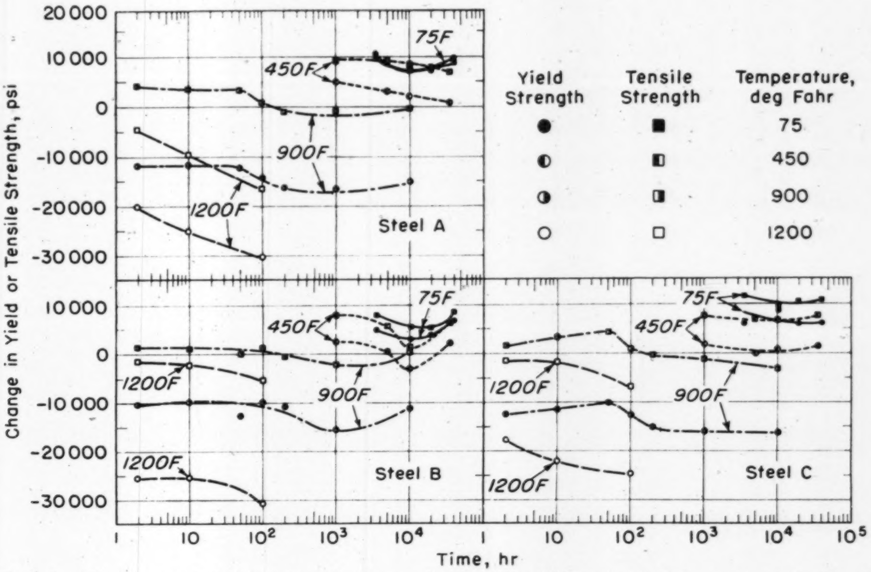

Fig. 6.—Changes in Yield or Tensile Strength of Material Strained Ten per cent in Tension With Time at 75 F and at 450, 900, or 1200 F After Fully Aging at 75 F.

Effect of Prestraining and Aging or Exposure at Elevated Temperatures on Tensile Properties:

The changes in yield and tensile strength for the prestrained material as a result of aging at 75 F, and of fully aging at 75 F and further aging at 450 F or exposing at 900 and 1200 F, are given in Fig. 6. Each experimental point is the average of two tests. For each steel the change in yield strength is the difference between the true stress at 10 per cent strain, which is taken as the average of at least two tests on hot-rolled material, and the stress at 0.2 per cent offset upon testing after aging. Similarly the change in tensile strength is the difference between the original tensile strength for the hot-rolled condition (this is the same as the tensile strength of the strained but unaged material) and the value observed after straining and aging, both of these quantities being related to an original area A_0, computed after 10 per cent strain in tension. This correction is employed to preclude a fictitious increase in tensile strength when using tension specimens with identical dimensions for as-received and prestrained material. This results from the fact that upon prestraining in tension and retesting in tension, the nominal stress on a prestrained specimen is greater than on a specimen of as-received material for any equivalent total strain when the original cross-sectional areas are identical.

In determining the effect of prestraining and aging on mechanical properties, it is important to point out that the additional factor of crystal recovery may be encountered. In general the effect of recovery on mechanical properties is in the opposite direction to that of strain-aging. Thus the total effect of strain-aging may be greatly reduced by the amount of recovery, depending on time and temperature. Different mechanical properties are known to be affected differently by strain-aging (8) and by recovery (9). It is found, for example, in most cases that the initial part of the stress-strain curve in tension is affected differently than the latter part by either strain-aging or recovery. The results in Fig. 6 indicate a similar behavior, since the change in yield strength differs in most cases from the change in tensile strength.

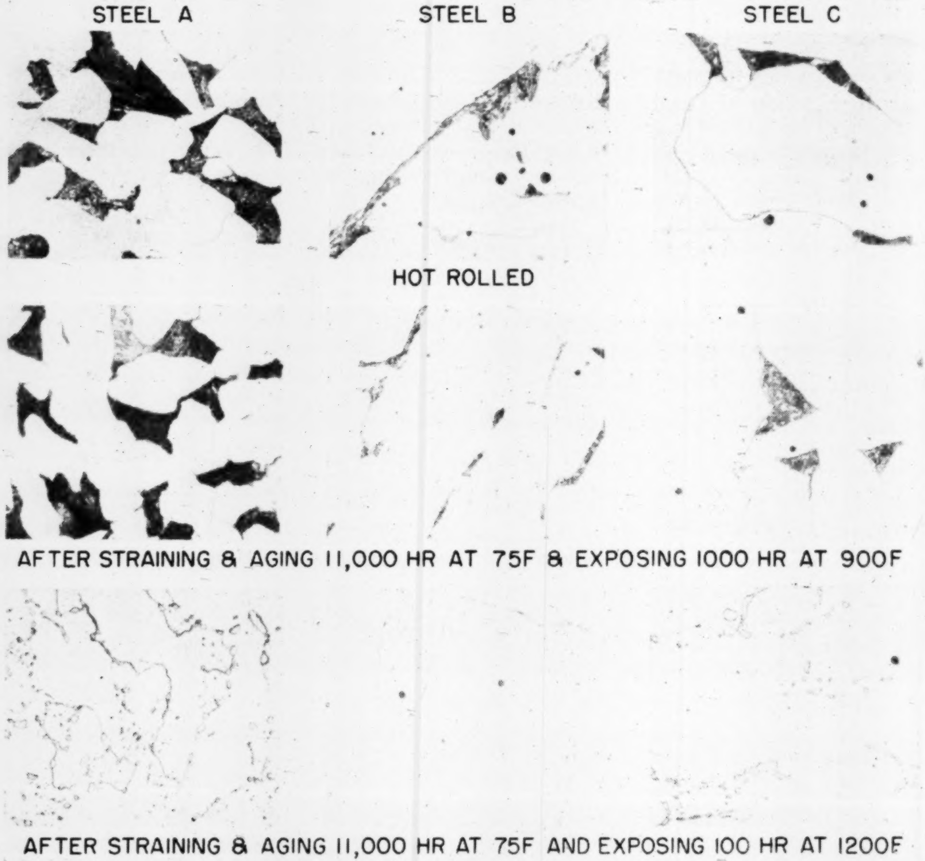
STEEL A
STEEL B
STEEL C
HOT ROLLED
AFTER STRAINING & AGING 11,000 HR AT 75F & EXPOSING 1000 HR AT 900F
AFTER STRAINING & AGING 11,000 HR AT 75F AND EXPOSING 100 HR AT 1200F

FIG. 7.—Microstructure of Steels in the Hot-Rolled Condition and After Straining and Aging at 75 F and Exposing at 900 and 1200 F.
(Nital Etch, ×1000) (reduced ½ in reproduction)

Both the yield and tensile strength of steel A are increased to the same extent by straining and aging at 75 F. As shown in Fig. 6, this is not the case for the other two steels. For steels B and C, the tensile strength increased by a greater amount. In the normalized condition, however, it was found for these steels that for shorter aging intervals the opposite is true (8). One other important feature of the results after aging at 75 F is that no pronounced over-aging tendencies are indicated.

After aging at 450 F the spread between the change in yield and tensile strength is much greater than after aging at 75 F. This behavior is undoubtedly related to the more pronounced effect of recovery at 450 F and to the fact that recovery seems to have a greater effect on the initial part of the stress-strain curve, that is, on the yield strength.

Recovery as well as other factors such as microstructural changes may also account for the even greater spread between yield and tensile strength values after exposure at 900 and 1200 F. Because of the limited knowledge of the structural changes which occur upon exposing prestrained and aged steels at 900 F, it is not possible to explain the unusual variation of the yield or tensile strength with time at this temperature.

Microstructural Changes:

Careful microscopic examinations and X-ray studies were made of all samples to detect structural changes associated with the changes in properties. Representative photomicrographs of the hot-rolled steels as well as after long exposures at 900 and 1200 F are shown in Fig. 7. No change was detected in any steel on aging at 75 or 450 F. Exposure at 900 F caused slight spheroidization, but at 1200 F extensive spheroidization in each steel was found. X-ray results indicated no recrystallization after exposure at 1200 F. No graphitization was noted in any instance.

Summary and Conclusions

The effect of aging time at 75 F on notch-impact transition-temperature range and on tensile properties after prestraining 10 per cent in tension has been determined. The effect of time on these properties has also been determined after straining and fully aging at 75 F followed by exposure at 450, 900, and 1200 F. The effect of normalizing material strained and fully aged at 75 F was also determined. The steels tested include a silicon-aluminum killed steel made by liquid metal practice, steel A; a capped open-hearth steel, steel B; and a capped bessemer steel, steel C.

Upon aging at 75 F it was found that the maximum shift in transition temperature, chosen arbitrarily at a level of 10 ft-lb., was least for steel B and slightly greater for steel A. Steel C showed a maximum shift somewhat greater than that for steel A. For each of these steels, however, the transition temperature after straining and aging is above the aging temperature, and some variable amount of aging at each test temperature may have occurred. Both impact and tensile results indicate that no over-aging occurs at 75 F within the aging times covered. The tensile results show that yield and tensile strengths are not increased by the same amount upon aging at 75 F.

Upon aging at 450 F, steel A exhibited a slightly greater maximum shift in transition temperature than steel B. Steel C exhibited a much greater shift. Again no tendency to over-age is indicated by the impact results. The tensile results indicate once more that the effect of aging on yield and tensile strength differs to some extent in magnitude; however, since at this temperature the effect of recovery is more pronounced, the effect of aging alone is not known.

Impact tests on material fully aged at 75 F showed that a slight improvement in notch-impact properties is obtained by subsequent exposure at 900 or 1200 F. However, stress relief treatments of this type do not eliminate to any great extent the effects of prestraining and aging. It is found that normalizing at 1650 F completely eliminates the effects of straining and aging.

Acknowledgments:

Grateful acknowledgment is made to W. B. Seens, W. L. Jensen, and E. K. Lynn for conducting all mechanical tests. The material was received in the hot-rolled condition from the National Tube Division of United States Steel Corp. The prestraining operation was done in the Metallurgical Department of the National Tube Works, McKeesport, Pa.

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EFFECT OF STRAIN-RATE HISTORY ON THE CREEP BEHAVIOR OF AN ALLOY STEEL AT 800 F*

By H. A. Lequear[1] and J. D. Lubahn[1]

Synopsis

Two groups of tests were made on a heat-treated Cr-Mo-V steel at 800 F. In one group most of a 0.3 per cent plastic prestrain was introduced in about 25 days on the average, and in the other group the same strain was introduced in only 40 min on the average. Then both groups were brought to a common stress. The quickly strained specimens had about 30 times the creep rate of the slowly strained specimens immediately after being brought to the common stress. This very definite rate history effect is in such a direction that strain aging would account for it; whereas the direction of the effect is opposite to what one would expect from earlier experiments by Dorn. Interrupted creep tests failed to reveal any strain-aging effects that could explain the observed rate history effect.

Dorn (**1**)[2] has shown a small, definite rate-history effect at a very low temperature; straining at a fast rate causes more strengthening than the same strain introduced at a slow rate. At higher temperatures there are no conclusive data to demonstrate either the presence or absence of rate-history effects when metallurgical changes do not occur. The lack of conclusiveness of most of the previous data is largely due to the fact that no attempt was made to determine whether or not there were metallurgical changes occurring under the conditions of testing.

From a recent investigation of Cr-Mo-V steel (**2**), it appeared that no metallurgical changes occur in this material at 800 F (although recovery did occur at 1000 F). The following describes an investigation intended to determine whether rate-history effects are present in Cr-Mo-V steel at 800 F, where metallurgical changes are apparently absent.

Material and Equipment:

Two lots of steel were used, differing slightly in composition and heat treatment. Although the earlier investigation (**2**) indicated that the lot I material did not suffer any metallurgical changes at 800 F, the results were very meager; consequently, additional tests were made on both lots of material in order to afford every possible assurance that metallurgical changes do not occur in this material at 800 F. These tests were similar to the previous tests (**2**), being creep

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* Presented at the Fifty-eighth Annual Meeting of the Society, June 26–July 1, 1955.

[1] Metallurgy Research Dept., Research Laboratory, General Electric Co., Schenectady, N. Y.

[2] The boldface numbers in parentheses refer to the list of references appended to this paper, see p. 723.

tests interrupted by an interval of time at zero stress. Both very long and very short periods of interruption were used, and at least two tests with each duration of interruption were made.

Of the two tests shown in Fig. 1, one test indicates that there is no effect of a short interruption, while the other indicates a slight strengthening (decrease of creep rate), if anything. Figure 2 shows that an interruption of 13 days apparently causes a small strengthening in lot I material, but no larger than the apparent strengthening observed in one test where the interruption was very short.

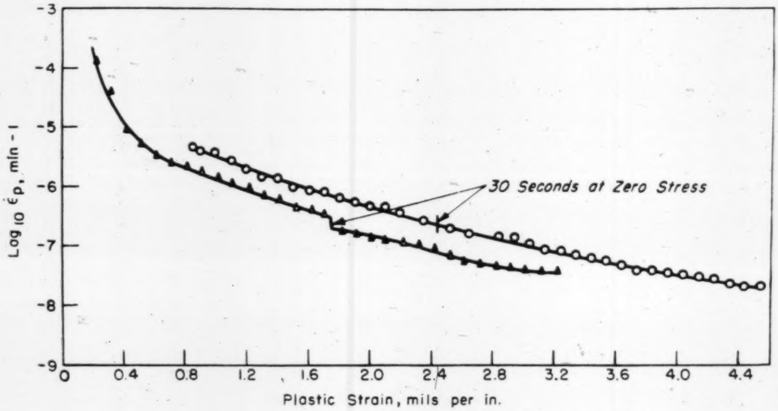

FIG. 1.—Two Creep Tests on Quenched and Tempered Cr-Mo-V Steel Interrupted by 30 sec at Zero Stress. 72,000 psi, 800 F, Lot I Material.

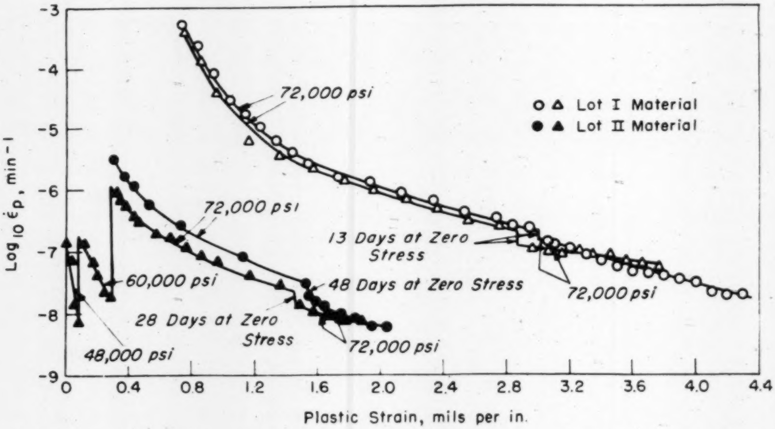

FIG. 2.—Interrupted Creep Tests on Quenched and Tempered Cr-Mo-V Steel. 800 F.

Figure 1 shows the results obtained on lot I material when the period of interruption was about 30 sec. Figure 2 shows similar data for interruptions involving many days. Figure 2 also includes tests on lot II material, as well as tests on lot I material. The results on lot II material will be discussed later.

It appears from these results that any possible strain-aging effects in the lot I material are no larger than the scattering in the test results. (The scattering might be due to small inaccuracies in the correction for the anelastic strains (3).) The lot II material shows effects in interrupted creep tests of about the same magnitude as those shown by the earlier material. It was because of this freedom from strain aging and recovery (apparent in Figs. 1 and 2) that this steel and testing temperature were selected for exploring the effect of rate history.

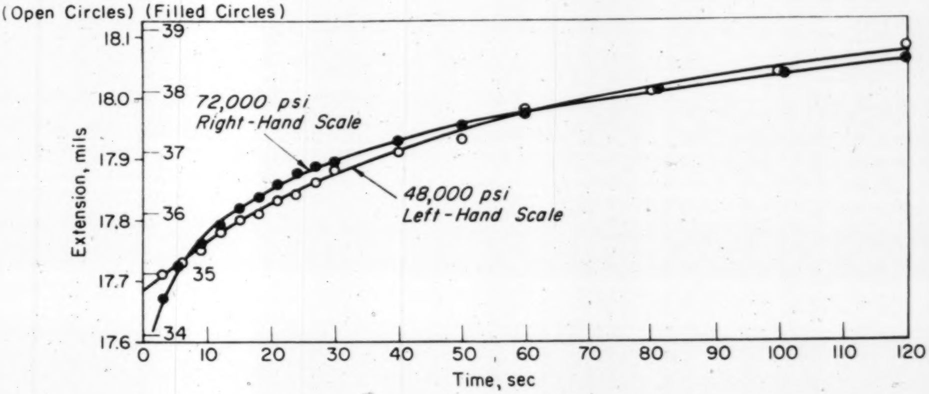

Fig. 3.—Comparison of Creep Behavior at Short Times for Two Different Loads. 800 F.

The equipment for the creep tests has been described (2). The specimens were 0.252 in. in diameter over a 10-in. gage length.

Testing Procedure:

Some difficulty was experienced in earlier tests in making accurate extrapolations from the first few data points back to the instant of loading for the purpose of determining the "zero" of creep strain. For large loads applied suddenly, the creep rate is initially so high and diminishes so rapidly that it is difficult to estimate within acceptable limits where the zero of creep strain lies. In order to avoid this difficulty, the final load was reached in three steps arranged to keep the initial creep rate reasonably small (see lowest curve in Fig. 2). Figure 3 illustrates that this improvement in technique results in a considerably more reliable value for the zero of creep strain.

TABLE I.—MATERIALS TESTED.

Composition, per cent		Heat Treatment
	Lot I	
Carbon	0.41	1650 F, 5 hr, oil, quenched as 3-in. rounds, 1240 F, 12 hr, furnace cooled, 1100 F, 5 hr, furnace cooled.
Chromium	0.99	
Molybdenum	0.58	
Vanadium	0.31	
	Lot II	
Carbon	0.45	1750 F, 5 hr, oi quenched as 3-in. rounds, 1240 F, 6 hr, furnace cooled, 1115 F, 4 hr, furnace cooled.
Chromium	0.90	
Molybdenum	0.54	
Vanadium	0.26	

In order to determine whether a rate-history effect exists, three specimens were allowed to creep to a certain strain in a long time at the comparatively low stress of 76,000 psi. Their creep rates were compared with those of three identical specimens that were brought to the same strain in a much shorter time by the use of a larger stress (86,000 psi) which was then reduced to the lower stress of 76,000 psi for the purpose of comparison. The comparison of creep rates was made on the basis of the plastic part of the strain, subtracting the anelastic component as described previously (3). In this case, however, in the range of plastic strains involved in the comparison, the plastic strains were so large compared to the anelastic effects that the conclusion would have been the same even if the results had not been corrected for the anelastic strain.

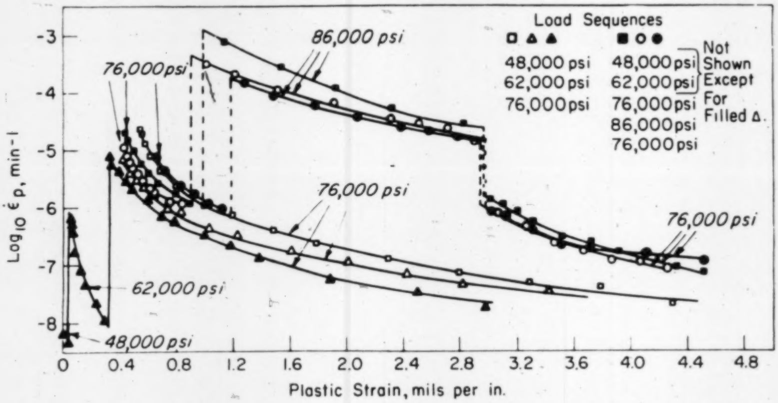

FIG. 4.—Comparison of Creep Behavio at a Common Load (76,000 psi) Following Rapid Straining in Three Tests and Slow Straining in Three Others. 800 F, Cr-Mo-V Steel, Lot II.

Experimental Results:

Figure 4 shows the results of the three long-time creep tests and the three companion bars that were brought to the same strain as the other three in a much shorter time, using a large load. About 1 mil per in. of plastic strain was introduced at the same series of loads in all six specimens (shown only in the lowest curve in Fig. 4). At 0.9 mils per in. of plastic strain there was a scattering among the six specimens corresponding to 5:1 variation in rate at 76,000 psi. Then, in three of the tests, the part of the plastic strain from the first to the third mil per inch was introduced at approximately one thousand times faster than in the other three tests (strain introduced in 27 to 53 min as contrasted to 17 to 35 days).

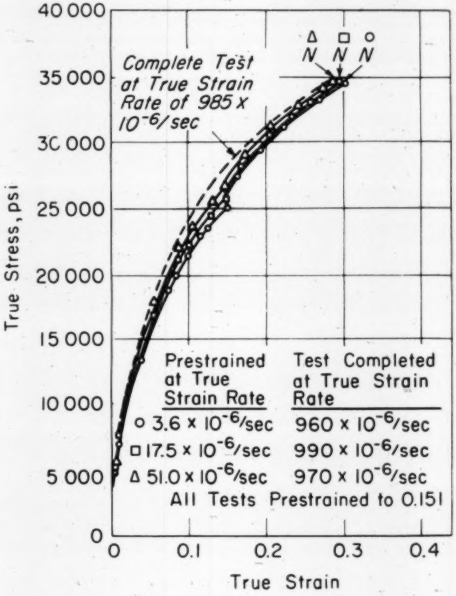

FIG. 5.—Effect of Strain Rate on the Work Hardening of 2S-O Aluminum Alloy at Liquid Nitrogen Temperature (78 K).

From Tietz and Dorn (1).

If the rate at which all or part of the prior strain was introduced had no effect on the subsequent deformation behavior, the rate-strain curves for all six tests should agree beyond 3 mils per in. of plastic strain, where the stresses are all identical (76,000 psi). It is clear from the figure that the subsequent behaviors were not the same. The specimens that were strained rapidly have creep rate values for a given strain and stress that are at least ten times those for the specimens strained slowly (and as much as thirty times immediately after diminishing the load). The conclusion from Fig. 4 is that a rate-history effect definitely does exist in Cr-Mo-V steel at 800 F.

Discussion of Results:

Figure 4 shows that the metal is stronger if it has been prestrained slowly than if it has been prestrained rapidly; that is, at a given stress it has a lower creep rate after slow prestraining than after rapid prestraining. This rate-history effect is opposite to that found by Dorn (1) on 2S-aluminum at liquid nitrogen temperature (Fig. 5).

The effect shown in Fig. 4 is in a direction that one would expect if strain aging were the cause. Thus, there is more opportunity for strengthening by strain aging during the longer time of prestraining at the low stress than during the shorter time at the higher stress. On the other hand, strain aging does not appear to be occurring to any appreciable extent in the times involved, according to Fig. 2. The strengthening effect, expressed as a decrease in creep rate of about 30 per cent in these interrupted creep tests, is many times smaller than the 10:1 effect observed in Fig. 4.

Of course, it is conceivable that strain aging still is the cause of the rate-history effect and that an interrupted creep test cannot reveal this strain aging. For example, if the strain aging were so rapid that it was continuously nearly complete, then only a small residual aging effect would occur during the interruption.

In summarizing, two things are to be pointed out. First, there is a real and definite rate-history effect in this Cr-Mo-V steel at 800 F. Secondly, if this rate-history effect is due to strain aging, the presence of such strain aging is not revealed by the tests used for this purpose, except possibly to a very slight extent.

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(3) J. D. Lubahn, "The Role of Anelasticity in Creep, Tension and Relaxation Behavior," *Transactions*, Am. Soc. Metals, Vol. 45, p. 787 (1953).

EFFECT OF SPECIMEN DIMENSIONS ON HIGH-TEMPERATURE MECHANICAL PROPERTIES*

By Paul Shahinian[1] and Joseph R. Lane[1]

Synopsis

The effect of changes in specimen dimensions on high-temperature properties of S-816 and monel alloys was investigated for specimens of various diameters and gage lengths. The diameters ranged from 0.1785 to 0.505 in. and the gage lengths from 0.25 to 4.0 in. The ratio of length to diameter varied between 0.5 and 16. Stress-rupture tests were conducted at 1500 F and 23,000 psi and 1100 F and 23,000 psi for S-816 and monel, respectively.

It is shown that increasing the ratio of length to diameter results in decreases in rupture time and total elongation for both metals. There is no effect of the ratio apparent on the minimum creep rate for monel; a general increase in the creep rate of S-816 is indicated with an increase in the ratio. The specific effects of changes in cross-sectional area and gage length are small if the ratio of length to diameter is maintained constant.

Since stress-rupture and creep tests are conducted to obtain design data, it is important to determine if the properties evaluated by these tests will vary markedly with changes in specimen size and shape. Data on the influence of size and shape are also essential for purposes of comparison because it is sometimes necessary or convenient to use specimens of different or odd sizes. Although several sizes of specimens are popular for stress-rupture tests, considerable freedom is still exercised in the selection of specimen dimensions. There is evidence in the literature[2,3,4] that an increase in cross-sectional area will cause an increase in time for rupture.

It was the object of the present study to evaluate the effect of changes in specimen dimensions on high-temperature mechanical properties. Changes in properties caused by variations in specimen dimensions may result from differences in the stress state of the test specimens, differences in the effects of the environment, or differences related to microstructural effects. A size effect related to grain structure is possible in a polycrystalline material since the grains at the surface are not constrained to the same extent as the inner grains. In addition, a size effect that is statistical in nature may occur in the initiation of fracture due to variations in the probability of the presence of defects.

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* Presented at the Fifty-eighth Annual Meeting of the Society, June 26–July 1, 1955.

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[2] J. Glen, "The Creep Properties of Molybdenum, Chromium-Molybdenum, and Molybdenum-Vanadium Steels," *Journal*, Iron and Steel Inst., Vol. 158, p. 37 (1948).

[3] L. W. Smith and P. K. Porter, "Utilization of Low-Alloy Materials for High-Temperature Service Applications," *Air Force Technical Report No. 6221*, Cornell Aeronautical Laboratory (1950).

[4] R. H. Thielemann and E. R. Parker, "Fracture of Steels at Elevated Temperatures After Prolonged Loading," *Transactions*, Am. Inst. Mining and Metallurgical Engrs., Vol. 135, p. 559 (1939).

PROCEDURE

Specimens of various diameters and gage lengths were tested in stress-rupture at high temperatures in air. The tests provided data on time to fracture, minimum creep rate, elongation at fracture, and reduction of area, and these quantities were then correlated with dimensional features of the specimens.

The investigation was conducted with two alloys—S-816, a typical high-temperature alloy, and monel, a single-phase alloy. Chemical compositions are shown in Table I. The materials were received in the form of rods of $\frac{7}{8}$-in. diameter (S-816) and $\frac{3}{4}$-in. diameter (monel) and given a heat treatment prior to testing. For S-816, the treatment consisted of holding at 2250 F for 1 hr, water quenching, and aging at 1400 F for 24 hr. A stable microstructure was obtained for monel by holding at 1500 F for 8 hr and air cooling. Measurement of grain size revealed an average grain diameter of 0.00187 in. for the S-816 alloy and an average grain diameter of 0.00305 in. for the monel alloy.

TABLE I.—CHEMICAL COMPOSITIONS OF ALLOYS, PER CENT.

	Cobalt	Nickel	Chromium	Copper	Carbon	Manganese	Silicon	Molybdenum	Tungsten	Columbium	Iron
S-816........	42.5	19.6	19.6	...	0.37	1.51	0.84	3.8	4.2	4.5	Balance
Monel.......	0.6	65.1	0.1	30.6	0.18	0.89	0.29	...	...	...	2.2

TABLE II.—SPECIMEN DIMENSIONS.

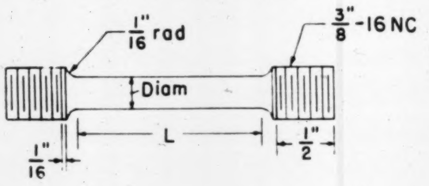
Diameter, in.	Cross-Sectional Area, sq in.	Gage Length, in.	Ratio of Length to Diameter
0.505.......	0.200	2.0	4.0
0.505.......	0.200	1.0	2.0
0.505.......	0.200	0.25	0.5
0.357.......	0.100	1.0	2.8
0.357.......	0.100	0.25	0.7
0.250.......	0.049	4.0	16.0
0.2525......	0.050	2.0	8.0
0.2525......	0.050	1.0	4.0
0.2525......	0.050	0.50	2.0
0.2525......	0.050	0.25	1.0
0.1785......	0.025	2.0	11.2
0.1785......	0.025	1.0	5.6
0.1785......	0.025	0.25	1.4

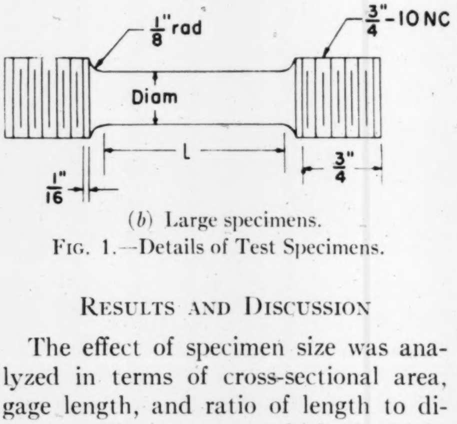
The dimensions of the test specimens ranged from 0.1785 to 0.505 in. in diameter and from 0.25 to 4.0 in. in gage length. Table II lists the various combinations of diameters and gage lengths used; however, all such combinations were not used for both alloys. The ratio of length to diameter of the specimens varied between 0.5 and 16. The details of the two types of specimens employed are shown in Fig. 1: type (*a*) was used for small diameter (0.1785 and 0.2525 in.) specimens, and type (*b*) was used for specimens of large diameter (0.357 and 0.505 in.). To keep the effect of the fillets (contribution to effective gage length) at a minimum, a small fillet radius was used.

The specimens were tested in single-lever, constant-load stress-rupture machines. Specimen temperature, measured by a chromel-alumel thermocouple tied to the center, was maintained to within ±2 F. The temperature gradient did not exceed 2 F along the gage length of the specimen. Specimens were at temperature approximately 12 hr prior to loading. The extension of each specimen was autographically recorded from the loading lever deflection, giving an elongation *versus* time curve; in addition, periodic readings were taken from a dial gage. Total extension was measured between the shoulders of specimens, and percentage elongation was calculated on the basis of actual gage length.

Tests were conducted on S-816 at 1500 F and 23,000 psi and on monel at 1100 F and 23,000 psi. Two to four tests were made on each specimen size of each alloy.

(*a*) Small specimens.





(*b*) Large specimens.

FIG. 1.—Details of Test Specimens.

RESULTS AND DISCUSSION

The effect of specimen size was analyzed in terms of cross-sectional area, gage length, and ratio of length to diameter. The extent to which the high-temperature properties—rupture time, minimum creep rate, total elongation, and reduction of area—were influenced by these factors was determined. Even though small radii were used for the fillets of specimens, no fractures were developed at the fillets. Microexamination of specimens before and after the test did not reveal a change in grain size.

The relationships of properties (except reduction of area) to the dimensional quantities are presented in Figs. 2 to 10. The points on these plots represent averages of the test results. Straight lines were drawn, wherever possible, to indicate the direction of the dimensional effects. In general, no attempt was made to draw curves through the individual points because of the small number of points available and the scatter in data inherent in stress-rupture testing.

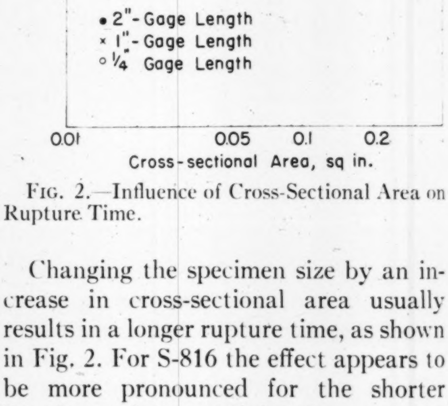


FIG. 2.—Influence of Cross-Sectional Area on Rupture Time.

Changing the specimen size by an increase in cross-sectional area usually results in a longer rupture time, as shown in Fig. 2. For S-816 the effect appears to be more pronounced for the shorter length specimens. Minimum creep rate is also affected by area but not in a consistent manner (Fig. 3). A decrease in creep rate with an increase in area was obtained with monel, whereas with S-816 only the shortest gage length specimens ($\frac{1}{4}$ in.) showed this behavior; the remainder of the tests indicated an increase in creep rate with an increase in

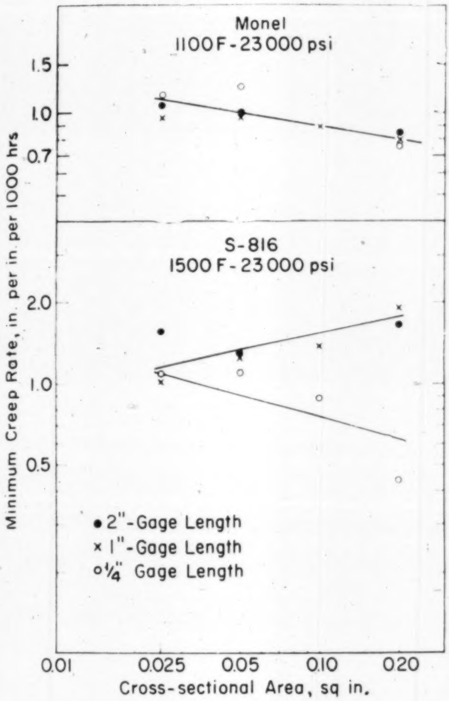


FIG. 3.—Influence of Cross-Sectional Area on Minimum Creep Rate.

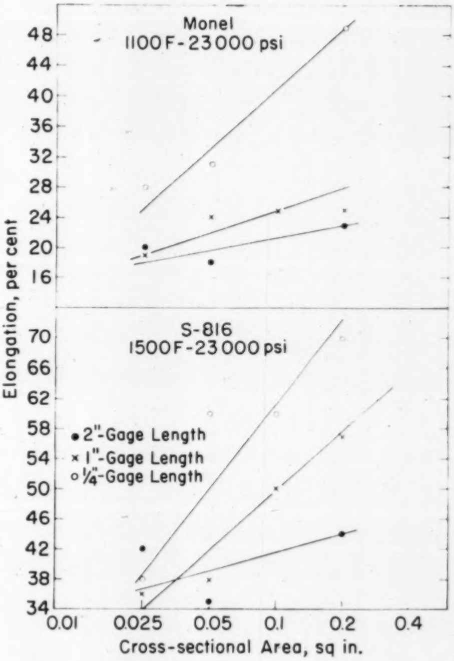


FIG. 4.—Influence of Cross-Sectional Area on Elongation at Fracture.

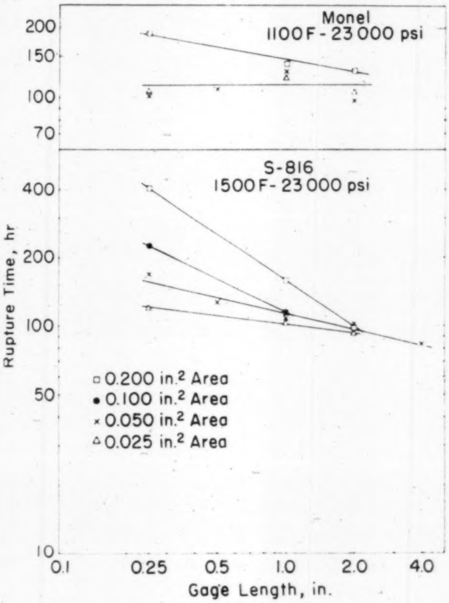


FIG. 5.—Influence of Gage Length on Time to Rupture.

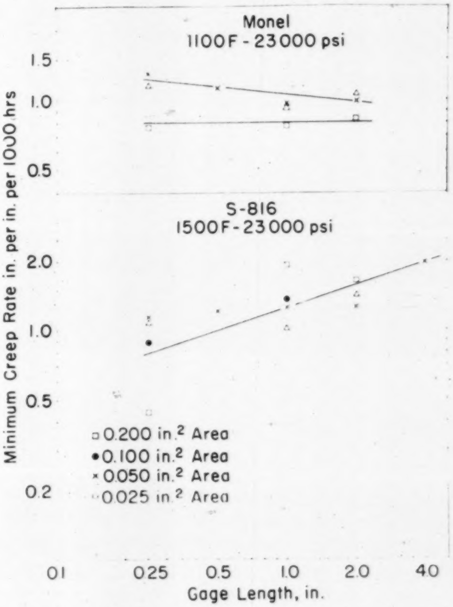


FIG. 6.—Influence of Gage Length on Minimum Creep Rate.

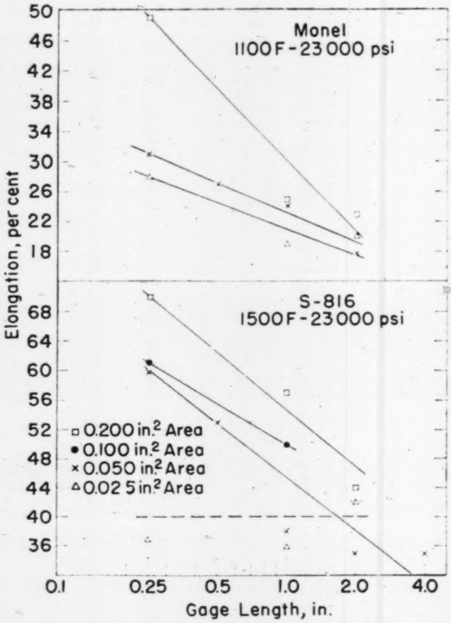


FIG. 7.—Influence of Gage Length on Total Elongation.

area. Increasing the cross-sectional area of the specimens produces higher total elongation values, as shown in Fig. 4, the influence being greater with the shorter specimens.

Decreasing the gage length of specimens results in no significant change in rupture times for monel specimens except those with the largest areas (Fig. 5). For S-816, a general increase that is most pronounced for the largest diameter specimens is indicated for all specimens. Figure 6 shows that the minimum creep rate decreases with increasing gage length for monel specimens, except for the largest diameter specimens which show no significant change of creep rate. For S-816, an increase in minimum creep rate with increase in gage length is observed. The percentage of total elongation, shown in Fig. 7, generally increases with decreasing gage length. Part of the effect may be attributed to the fact that

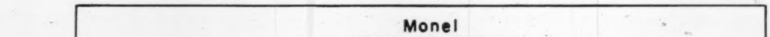


FIG. 8.—Relationship Between Length-to-Diameter Ratio and Rupture Time.

creep in the fillets of shorter specimens is a larger percentage of the total creep.

An "end" effect arising from the restraint of flow due to the shoulders becomes important in short specimens. The stress pattern is such that lateral flow is restricted, a condition that consequently influences the measured properties. The correlations between the ratio of gage length to diameter and the various properties are presented in Figs. 8, 9, and 10.

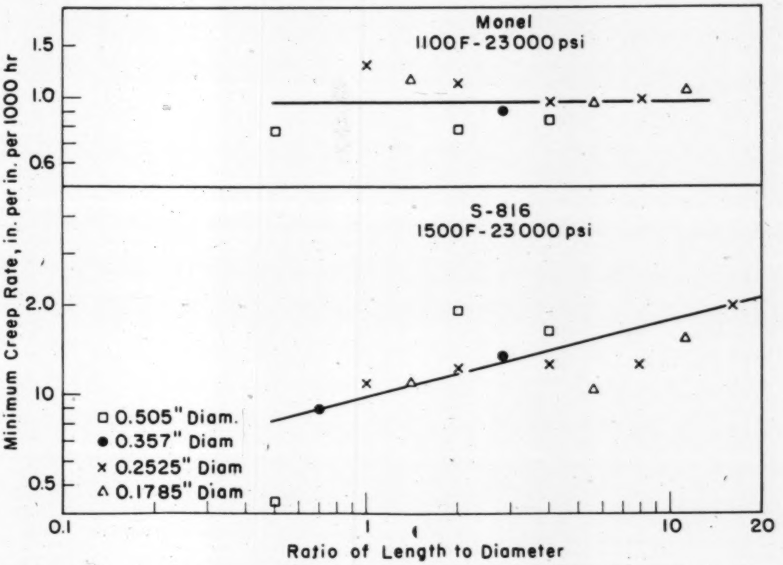


FIG. 9.—Relationship Between Length-to-Diameter Ratio and Minimum Creep Rate.

A general increase in rupture time with a decrease in the ratio of length to diameter is observed in Fig. 8. The change in rupture time for monel is small compared to that for S-816. The sharp gain in rupture time with a decrease in ratio values below 4 for S-816 is probably due to the increasing role of the "end" effect. It is observed that rupture times of various size specimens are comparable if their length-to-diameter ratios are the same.

The ratio of length to diameter has no apparent effect on the minimum creep rate of monel (Fig. 9); for S-816 a general increase is indicated with an increase in this ratio. On the basis of the data, it does not appear that the minimum creep rates of various size specimens can be compared with reliability. With 0.505-in. diameter specimens, there is a definite divergence from the general trend. The effect of variation of the length-to-diameter ratio on the percentage elongation after fracture, shown in Fig. 10, is very pronounced. Higher elongations for lower values of the ratio are obtained for both the S-816 and monel. It appears that elongation values of specimens of the same ratio are reasonably close in most cases; however, S-816 specimens of the smallest diameter, 0.1785 in., did not give conformable results.

In general, reduction-of-area values were not affected in a consistent manner by changes in cross-sectional area, gage length, and length-to-diameter ratio. The values for monel did not differ greatly, ranging from 22 to 29 per cent, whereas the range for S-816 was 40 to 63 per cent. The scatter in data, particularly for S-816, was too great to permit conclusions to be drawn, and the data consequently are not presented. Difficulty in accurately measuring the reduction of area may have been a contributing cause to the scatter.

CONCLUSIONS

The most significant points of this study may be summarized as follows:

1. Changes in cross-sectional area, gage length, and length-to-diameter ratio affected the properties of S-816 and monel alloys to different degrees and sometimes in a different manner.

2. The correlation of length-to-diameter ratio with rupture time and elongation points out the importance of this quantity in considering dimensional effects. As the ratio of length to diameter increases, time to rupture and total elongation decrease for both metals. The effect on elongation is especially pronounced.

3. There is no effect of the ratio apparent on the minimum creep rate for monel; a general increase for S-816 is indicated with an increase in the ratio.

4. In general, specimens with identical length-to-diameter ratios have approximately the same rupture times and elongations. If identical size specimens cannot be used for a series of tests, it appears advisable to use specimens with the same length-to-diameter ratio. The smallest difference in rupture time and the least scatter are developed in the ratio range of 4 to 8.

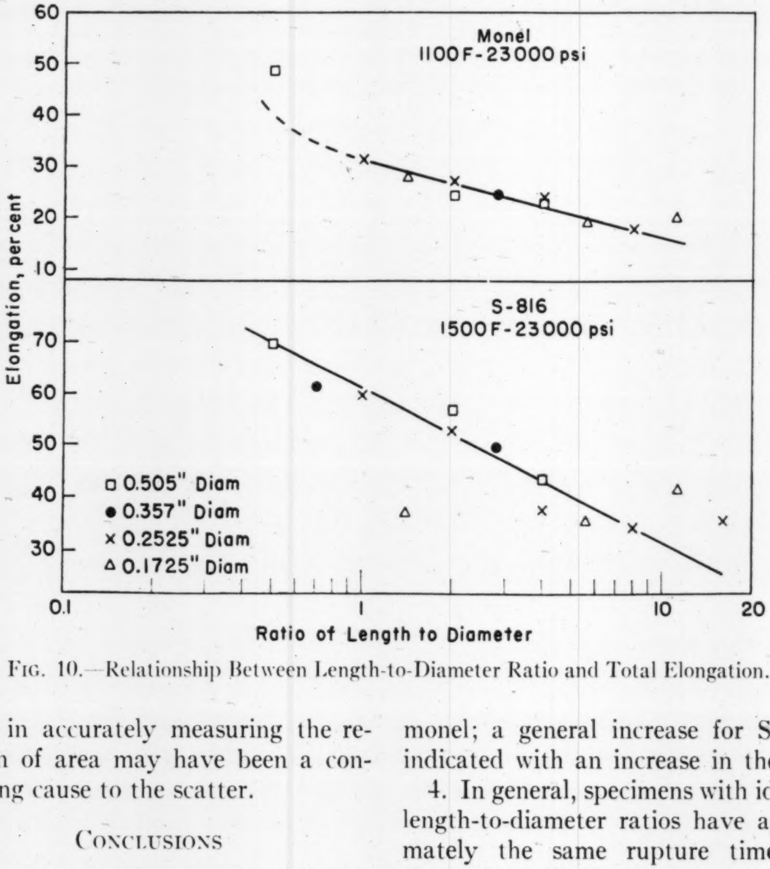


FIG. 10.—Relationship Between Length-to-Diameter Ratio and Total Elongation.

Acknowledgment:

The authors wish to express their appreciation to W. S. Pellini for his helpful suggestions.

DISCUSSION

Mr. A. H. Kidder.[1]—Why was 1100 F chosen for one sample and 1500 F for the other? It seemed to me that perhaps some of the differences between monel and the other material might have been due to the different temperatures used.

Mr. Paul Shahinian (*author*).—I agree that it may be a reason for the difference. However, one should not necessarily expect two different materials to exhibit the same behavior when tested at the same temperature.

The reason that the lower temperature was selected for the monel is that at 1500 F you get very severe oxidation, whereas at 1100 F temperature the oxidation was not severe and the behavior was of a type that one might expect at high temperatures.

For the S-816 we used 1500 F which is a common temperature for testing this material. I believe that if you test at 1100 F you might be getting into the range of low-temperature behavior.

Mr. B. R. Hubbard.[2]—I should like to explore the question of temperature a little further. Suppose you took the monel samples and treated them at other temperatures. Is the 1100 F curve typical of what one could expect to get for other temperatures; or has there been no opportunity to make tests at other temperatures? The same question applies to the tests on the S-816 samples.

Mr. Shahinian.—It is quite possible that the behavior at other temperatures would be different. The test temperatures were selected to be in the region of high-temperature behavior for the materials.

Mr. John J. Crowe.[3]—I should like to ask what method was used in drawing the curves.

In a number of cases where the authors showed quite a slope in the curve, it looked as though a straight line would have satisfied the points as well as the sloping line used.

Mr. Shahinian.—That is a very good point. There was considerable scatter in these data and we drew what we considered to be reasonable curves, and it is quite possible that someone else may draw a line of a slightly different slope.

Mr. Crowe.—In every case, a great deal more weight was given to the right-hand point on the curves for the 2-in. specimen than to the other observations. The curve goes through the right-hand point every time.

Mr. Shahinian.—A closer look at the graphs will show that the right-hand points were not weighted in drawing the curves.

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[1] Engineer in Charge of Testing Division, Philadelphia Electric Co., Philadelphia, Pa.

[2] Assistant Vice-President, Triangle Conduit and Cable Co., New Brunswick, N. J.

[3] Assistant Vice-President, Air Reduction Co., Union, N. J.

COMPRESSION-CREEP PROPERTIES OF SEVERAL METALLIC AND CERMET MATERIALS AT HIGH TEMPERATURES*

By L. A. Yerkovich[1] and G. J. Guarnieri[1]

Synopsis

Compression-creep testing apparatus has been designed and constructed for testing of metals and metal-ceramic materials at temperatures up to 1800 F. Compression-creep data of several hundred hours' duration were procured for wrought S-816 and Nimonic 90 at 1350 and 1600 F, arc-cast and swaged molybdenum at 1600 F, cast Haynes Stellite 21 at 1600 F, and the cermets K162-B at 1800 F and Metamic LT-1 at 1600 F.

Although only limited comparisons of the compression-creep results were made with tension-creep behavior, certain trends were indicated. It would appear that wrought bar material could display poorer creep resistance in compression than in tension due to fabrication history, whereas cast metals would have little difference in compression- and tension-creep strength. Metal-bonded ceramics are considerably stronger in compression than in tension.

For the most part, the high-temperature creep-strength properties of materials have been evaluated by simple tension loading tests conducted at constant temperature and for various time durations. In the past, such data, in conjunction with suitable stress analysis procedures and ample safety factors, have been used successfully to design structural assemblies subjected to various loading conditions other than tension.

More recently several trends have developed which have stimulated interest in the actual compression-creep properties of engineering materials. The never-ending demand for decreased weight-to-strength ratios in aircraft, coupled with the high-temperature conditions currently encountered, has created a creep-buckling problem in the design of the resulting thin-walled structures. Compression-creep data are of considerable value in the methods developed for handling this problem (**1**).[2]

The vigorous development of the cermet type of material for high-temperature use in jet aircraft and rocket motors is another reason for the interest in compression-creep testing methods and material data. While it is hoped that the cermets may eventually be used for such tension applications as turbine buckets by development of improved thermal-shock and impact-resistant compositions, their inherently high compression strengths

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[2] The boldface numbers in parentheses refer to the list of references appended to this paper, see p. 754.

are of particular interest. Because of the specimen-gripping difficulties encountered in the tension testing of such relatively brittle materials, it has been suggested that compression testing might be a more convenient method of evaluating the relative high-temperature strength properties of fragile materials.

Although a reasonable amount of short-time high-temperature stress-strain compression data has been accumulated, only few compression-creep results exist. Sully (2) and also Allen and Carrington (3) have reported data for several alloys and refractory metals, respectively. Since, in these tests, the total specimen length was only $\frac{1}{4}$ in., simple compression loading did not exist because of the end restraints. The test apparatus and data were used primarily for relative comparison of various materials. Carlson and Schwope (4) have conducted a limited study of the compression-creep behavior of stabilized 2024-T4 aluminum at 350 and 450 F.

Because of the general familiarity with and the availability of tension-creep data, it is of interest to compare compression- *versus* tension-creep behavior of materials where possible. Sully (2) has noted greater primary creep in compression than in tension but suspected this to be an effect due to "bedding-down" of the specimen ends rather than a true metal behavior. He finds that for metallic materials of reasonable ductility the compression-creep test gives results that agree well with tension-creep behavior in the secondary stage of creep and usually in the time to onset of accelerating creep. Allen and Carrington (3) also state that in general the primary creep strain up to 0.5 per cent occurs faster in compression than in tension.

It has been possible to date to make only limited tension- *versus* compression-creep comparisons of the materials investigated in this study. Under sponsorship of the Wright Air Development Center, a more comprehensive program in this respect is under way at the Cornell Aeronautical Laboratory. It has been the main objective of the investigation to date to develop suitable test apparatus and to obtain compression-creep data for various metals and cermets.

TEST MATERIALS AND PROGRAM

Various alloy and metal-ceramic compositions which represent a range of high-temperature strengths and ductilities have been chosen for compression-creep testing. In addition, the materials selected for the investigation represent a variety of manufacturing processes in that wrought and cast alloys are included as well as compacted and slip-cast metal-ceramics. Compression-creep properties have been determined at several stress levels to establish time-deformation and stress-time relationships in the temperature range from 1350 to 1800 F for compression-creep strains up to 5 per cent for times of a few hours up to several hundred hours.

The materials employed in the test program, along with the pertinent descriptions of their procurement and treatment prior to testing, include the following six alloys and cermets. The compositions are indicated in Table I.

(*a*) *Wrought Test Materials:*

S-816—Received from Allegheny Ludlum Steel Corp. as wrought $\frac{1}{2}$-in. bar stock, annealed, and pickled.

Nimonic 90—Received from International Nickel Co., Inc., as hot-rolled, $\frac{1}{2}$-in. bar stock.

Molybdenum—Received from Westinghouse Electric Corp. as $\frac{1}{2}$-in. bar swaged from arc-cast ingot.

Because of the poor resistance to oxidation of molybdenum at the test temperature, a protective coating ade-

TABLE I.—TEST MATERIALS AND THEIR CHEMICAL COMPOSITIONS.

Material	Material Condition	Chemical Composition, per cent												
		Carbon	Manganese	Silicon	Chromium	Nickel	Molybdenum	Cobalt	Iron	Sulfur	Phosphorus	Tungsten	Copper	Others
S-816	Wrought bar annealed	0.36	1.22	0.41	19.76	19.92	3.85	43.23	3.36	0.016	0.014	4.12		Columbium + tantalum 3.74
Nimonic 90	Wrought bar	0.04	0.30	0.15	20.18	55.18		20.37	0.46	0.007		Aluminum 1.01	0.04	Titanium 2.24
Molybdenum	Arc-cast swaged bar	0.06		Trace			99.90 minimum		Trace				Trace	
Haynes Stellite 21	As-cast	0.30			27.50	2.50	5.50	Balance	2.00 maximum					
Kennametal K162-B	Pressed and sintered	Titanium carbide 62.00				25.00	5.00							Columbium (SS)[a] 8.0
Metamic LT-1	Slip-cast and sintered				77.00									Aluminum-oxide 23.00

[a] Solid solution.

quate for service up to 1800 F for several hundred hours was applied to the molybdenum specimens by the Research Laboratory of the Climax Molybdenum Co. of Michigan. The protective coating procedure consisted of blasting the specimens with coarse aluminum oxide to assist in mechanical bonding between the specimen and the coating. The specimen was rotated while a 0.10-in. thick metal-sprayed alloy coating of 55.96 per cent chromium, 40.55 per cent silicon, 1.40 per cent iron, 0.44 per cent aluminum was applied. A subsequent heat treatment at 2000 F in a purified hydrogen atmosphere for 2 hr was employed to densify the coating and to obtain a diffusion bond between the coating alloy and the molybdenum specimen.

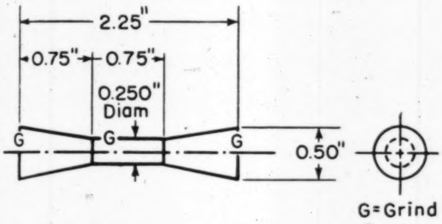

FIG. 1.—Static Compression-Creep Test Specimen.

NOTE.—Machine and grind ends; must be 90 deg to the axis of the specimen. Machine and grind cylindrical portion of specimen; must be concentric and parallel with axis of specimen along its entire length.

(*b*) *Cast Test Material:*

Haynes Stellite 21—Received from Haynes Stellite Co. as finished specimens machined from cast bars.

(*c*) *Metal-Ceramic Test Materials:*

Kennametal K162-B—Received from Kennametal, Inc., as finished specimens prepared from comminuted carbide and metal powders hydrostatically pressed and sintered to a nominal density of 6.0 g per cu cm.

Metamic LT-1—Received from Haynes Stellite Co. as finished specimens prepared from a slurry of oxide and metal powders, slip cast and sintered. Nominal density of the sintered mixture is 6.0 g per cu cm.

TEST SPECIMEN

It is well known that, in compression testing, eccentricities in load application have a tendency to increase, especially as the specimen is plastically deformed, whereas in tension loading eccentricities tend to decrease with increasing deformation. From a theoretical standpoint, more uniform stress distribution could be obtained in tension if the test specimen were slender and infinitely long. Conversely, in compression the ideal specimen should be stout and relatively short. However, from a practical point of view, limitations and standards such as those suggested by the ASTM must be placed on specimen sizes and shapes so that comparative values of material properties may have significance. Although specifications or tentative specifications have been established in the preparation of specimens for room-temperature tension and compression testing and tension creep-rupture testing of metals, there exists no such prescribed procedure for the preparation of specimens for conducting compression-creep tests on either metallic or metal-ceramic materials. As a consequence, the choice of specimen may be based upon the considerations of testing ease and available machine capacity.

LaTour and Wolford (5) observed that in the room-temperature compression testing of sheet material an effect which results in the bulging of the specimen ends is created by large shear deformations converging from the specimen corners. In order to overcome the influence of end effect, Osgood (6) recommends that the compression deformation be measured over a central gage length of the specimen, the center 1-in. section of a $2\frac{1}{4}$- to $2\frac{1}{2}$-in. long specimen, for example. In addition, to obtain stability

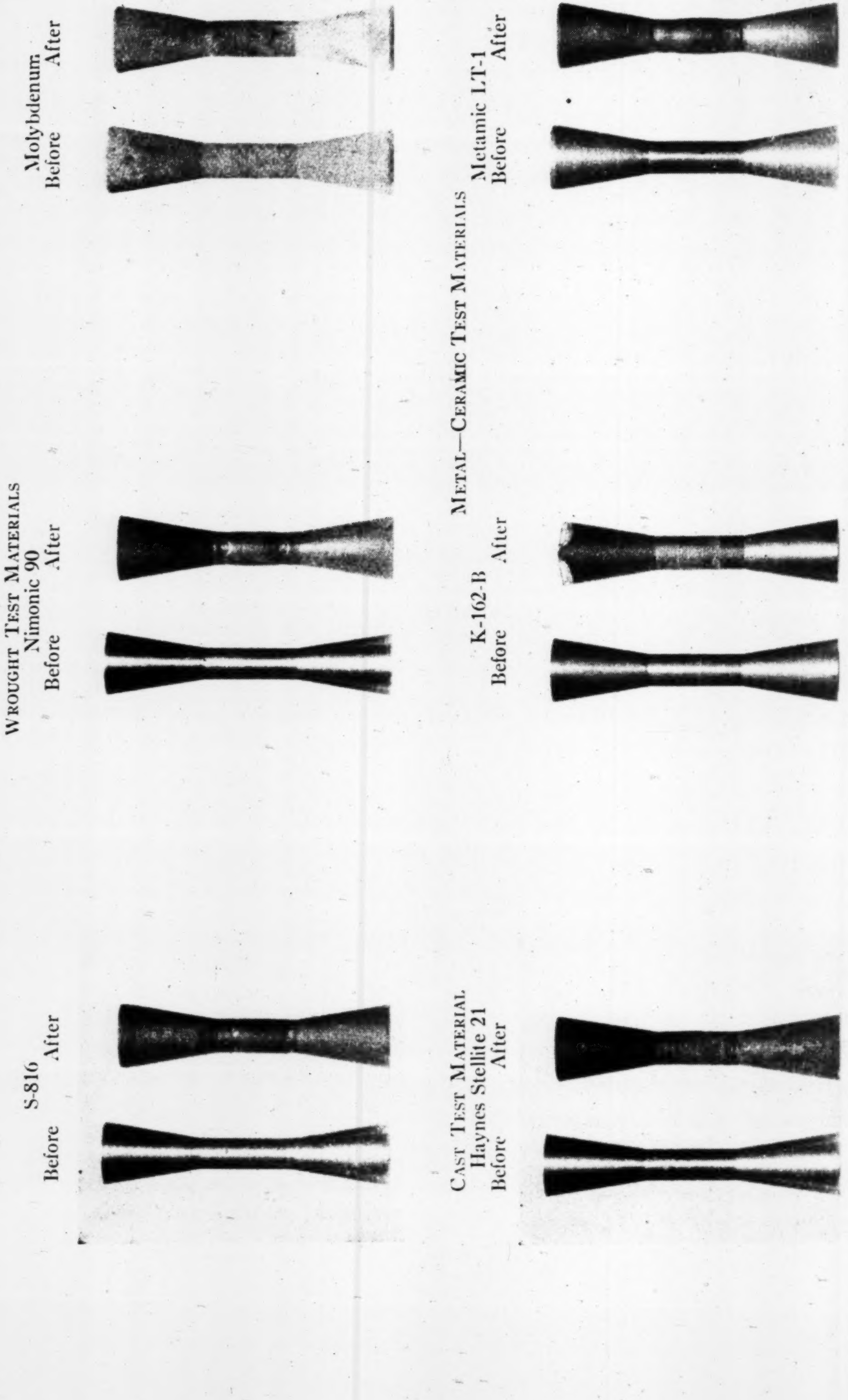
S-816
Before
After
WROUGHT TEST MATERIALS
Nimonic 90
Before
After
Molybdenum
Before
After
CAST TEST MATERIAL
Haynes Stellite 21
Before
After
METAL—CERAMIC TEST MATERIALS
K-162-B
Before
After
Metamic LT-1
Before
After

FIG. 2.—Static Compression-Creep Test Specimens Before and After Compression-Creep Testing at Elevated Temperatures.

against buckling and thus more accurately determine compression properties, it is suggested that a ratio of total specimen length to minimum thickness of 3 to 4 not be exceeded (7) and that the bearing ends be machined to very close tolerances such that they are mutually perpendicular to the specimen axis (8).

For the purpose of this investigation, a specimen was designed that attempted to overcome the inherent difficulties associated with the compression testing of a variety of types of materials. This specimen is illustrated in Fig. 1. Because deformation of the ends, if nonuniform, will alter the stress pattern in the specimen and result in eccentric loading, conically tapered ends have been included in the specimen design to reduce the stress on the bearing surfaces. The machined and ground cylindrical section of the specimen, located midway between

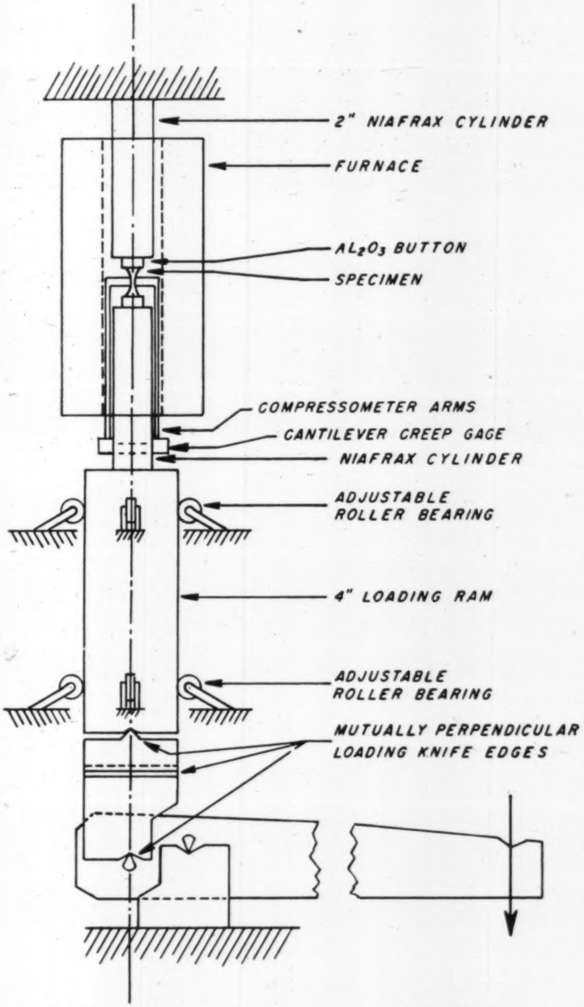
2" NIAFRAX CYLINDER
FURNACE
AL_2O_3 BUTTON
SPECIMEN
COMPRESSOMETER ARMS
CANTILEVER CREEP GAGE
NIAFRAX CYLINDER
ADJUSTABLE ROLLER BEARING
4" LOADING RAM
ADJUSTABLE ROLLER BEARING
MUTUALLY PERPENDICULAR LOADING KNIFE EDGES

Fig. 3.—Schematic Diagram of Compression-Creep Test Equipment.

the conical ends, provides the necessary test section for determining the deformation characteristics in compression. Even though the over-all specimen length to minimum diameter ratio is in excess of 3, satisfactory performance has been obtained without buckling for creep deformation up to 5 per cent. It will, however, be observed that the 3 to 1 ratio has been maintained in the gage-length test section. In accordance with the machining requirements, the bearing surfaces are specified to be parallel within 0.0005 in. and perpendicular to the axis of the test section. Typical examples of the test materials before and after compression-creep testing are represented in Fig. 2.

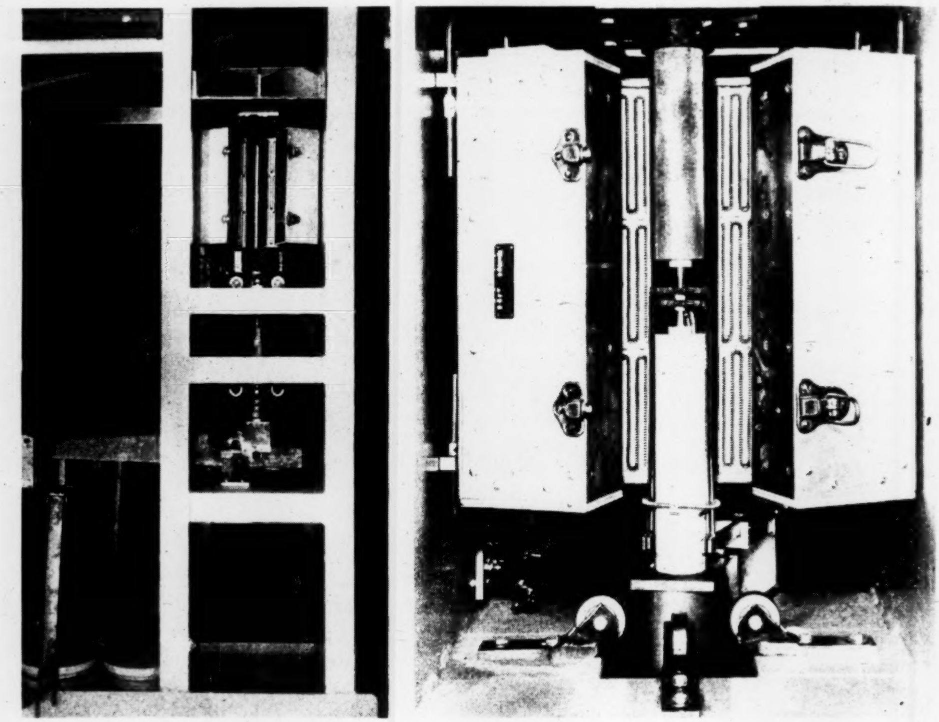

FIG. 4.—Static Compression-Creep Test Unit with Close-Up of Furnace Zone Illustrating Position of Specimen for Testing.

TEST EQUIPMENT AND PROCEDURE

In the development of equipment for compression testing, considerable care must be taken in the construction and assembly of components in order to insure axial alignment of load application to the specimen. Such precautions are of particular importance in the case of compression loading because of the tendency for all materials to buckle.

When conducting compression tests, it is important that the travel of the movable crosshead of the loading equipment be maintained in a straight line at right angles to the stationary crosshead. Since this requirement is often difficult to achieve, compression subpresses associated with the test specimen are very often used in conjunction with the load-applying apparatus. Although a subpress is well suited for performing room-temperature compression tests, at elevated temperatures its mass greatly increases the problem of obtaining and maintaining equilibrium test temperatures.

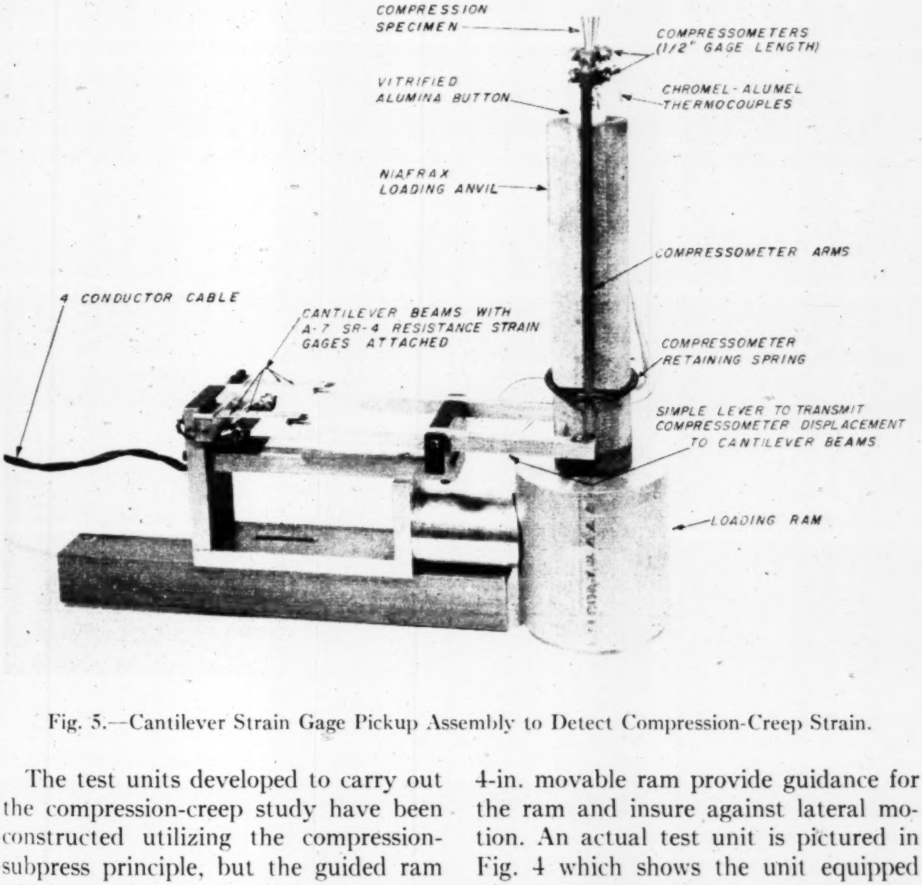
COMPRESSION SPECIMEN
COMPRESSOMETERS (1/2" GAGE LENGTH)
VITRIFIED ALUMINA BUTTON
CHROMEL-ALUMEL THERMOCOUPLES
NIAFRAX LOADING ANVIL
COMPRESSOMETER ARMS
4 CONDUCTOR CABLE
CANTILEVER BEAMS WITH A-7 SR-4 RESISTANCE STRAIN GAGES ATTACHED
COMPRESSOMETER RETAINING SPRING
SIMPLE LEVER TO TRANSMIT COMPRESSOMETER DISPLACEMENT TO CANTILEVER BEAMS
LOADING RAM

Fig. 5.—Cantilever Strain Gage Pickup Assembly to Detect Compression-Creep Strain.

The test units developed to carry out the compression-creep study have been constructed utilizing the compression-subpress principle, but the guided ram which applies the load is completely divorced from the furnace. The loading equipment consists of a welded frame made of 18-in. ship channel for rigidity. Sturdy load-transmission members capable of being adjusted are incorporated in the test unit assembly. Figure 3 presents a schematic diagram to illustrate the manner of load application and equipment operation. Load is applied to the specimen by a 20:1 static loading lever which acts through a series of knife-edges arranged alternately perpendicular between the loading lever and the movable ram. Four sets of adjustable roller bearings at the top and bottom and spaced at 90-deg intervals around a 4-in. movable ram provide guidance for the ram and insure against lateral motion. An actual test unit is pictured in Fig. 4 which shows the unit equipped with furnace for high-temperature testing. Since load-transmission members must extend into the furnace, which is being heated to maintain the specimen test section at temperatures up to 1800 F, a material capable of exposure to elevated temperature without deforming appreciably under load had to be selected for this purpose. These upper and lower loading anvils, between which the specimen is sandwiched, consist of Niafrax (silicon carbide) cylinders 2 in. in diameter; they extend from the hot zone of the furnace to engage the fixed head and the movable ram outside the furnace. One-inch diameter buttons of vitrified alumina, which display excellent deformation resistance at high temperatures, are inserted between the test specimen and the Niafrax cylinders to reduce the unit stress on the loading surfaces of the cylinders.

The test temperature is maintained by a 5 kva, three-zone, resistance-wound furnace, vertically split to accommodate insertion of the test specimen. The furnace is regulated, to provide high- and low-voltage input, by a conventional potentiometric temperature controller capable of maintaining specimen temperature within limits of ±3 F of the nominal test temperature. Each zone of the furnace is separately powered by an autotransformer making it possible to adjust test temperature and temperature distribution over the $\frac{3}{4}$-in. specimen test section. Temperature measurements are made at the top, middle, and bottom gage sections with calibrated chromel-alumel thermocouples wired to the specimen at those positions and shielded from furnace radiation by asbestos cord. A precision potentiometer accurate to within $\frac{1}{2}$ F is used to indicate the test-section temperature and to serve as a guide for temperature adjustments.

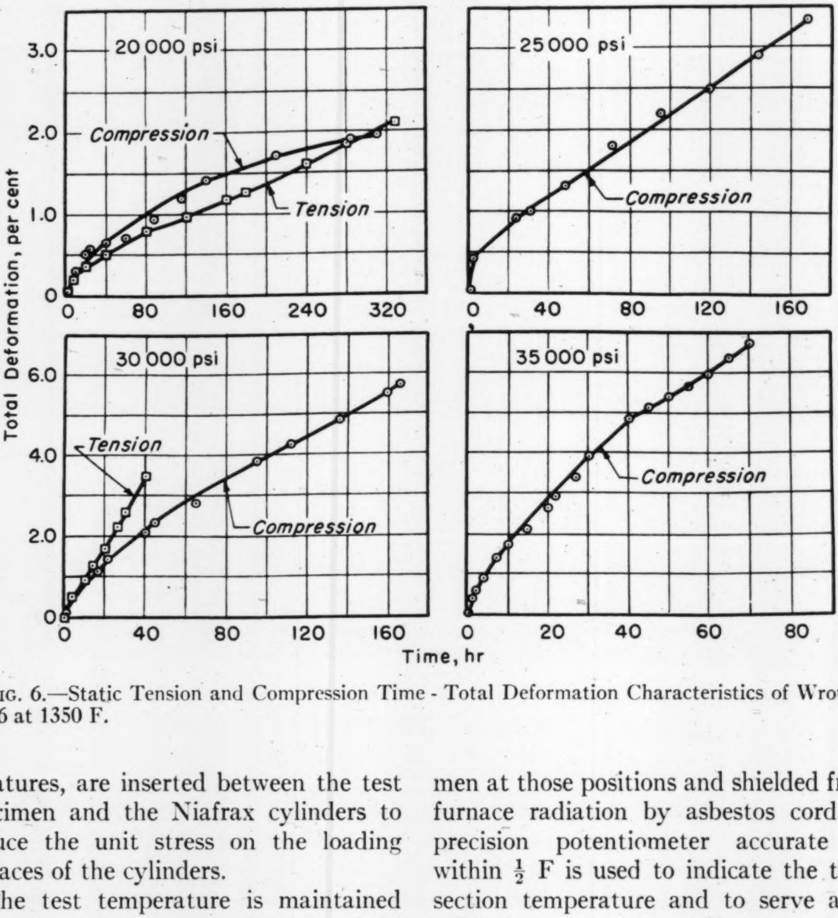

FIG. 6.—Static Tension and Compression Time - Total Deformation Characteristics of Wrought S-816 at 1350 F.

Specimen strain is measured over a $\frac{1}{2}$-in. test section by a set of compressometers attached to the specimen and extending outside the lower end of the furnace. These compressometers, consisting of an upper and lower pair, engage at their lower end simple levers which transmit the compressometer motion to cantilever beams on which resistance strain gages are cemented. The relative displacement of the upper and lower compressometers, being a direct measure of the creep deformation, is detected as an unbalance in an electrical bridge circuit. Precalibration of the cantilever beams and the bridge circuit permits convenient and accurate conversion of the generated bridge unbalance into creep strain. Continuous record of the creep strain is made on a Dynalog-type strain recorder with the over-all system having a long-time accuracy of 0.0007 in. per in. and a sensitivity of 0.00007 in. per in. This method of detecting the compression-creep strain is illustrated in Fig. 5, which shows the essential features in the specimen-compressometer assembly.

Where tension-creep tests were made for comparison purposes, a conventional lever-loading unit was used with temperature control and strain-measuring systems of the type and accuracy described for compression. Tension-creep specimens were used with threaded ends and a gage section $\frac{1}{4}$ in. in diameter and 2 in. long.

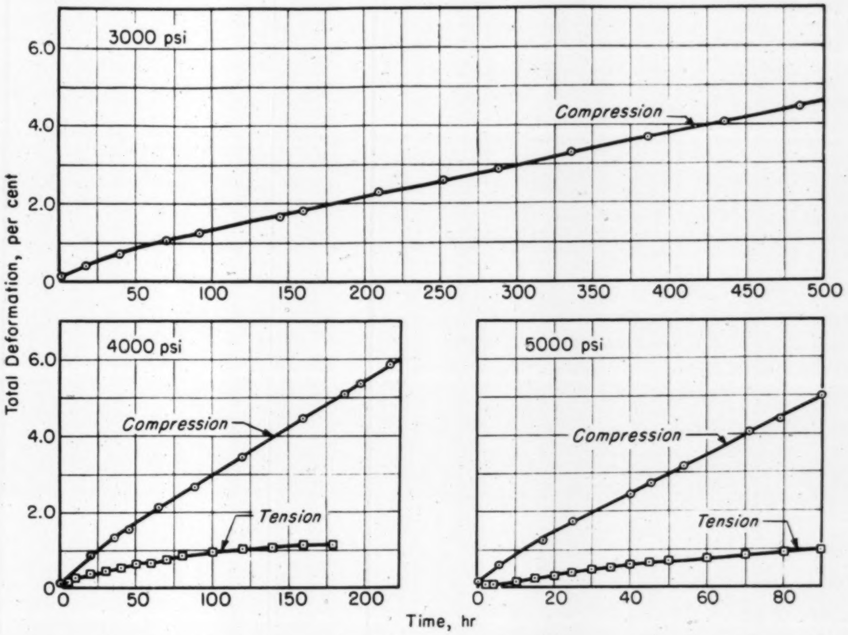

FIG. 7.—Static Tension and Compression Time - Total Deformation Characteristics of Wrought S-816 at 1600 F.

TEST RESULTS

Wrought Alloys:

S-816.—The wrought $\frac{1}{2}$-in. bar of S-816 was subjected to static compressive stresses, applied parallel to the direction of working, at 1350 and 1600 F. Curves representing the deformation characteristics of this alloy are presented in Figs. 6 and 7 relating time to total deformation for the selected stress at both test temperatures. The conventional design-type curves relating stress and time for various amounts of creep and total deformation are presented in Fig. 8 for 1350 F and Fig. 9 for 1600 F.

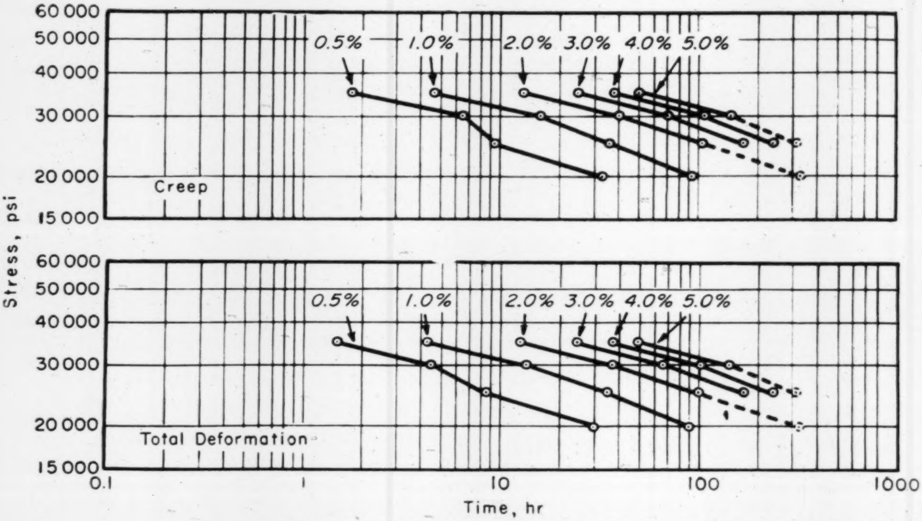

Fig. 8.—Static Compression-Creep and Total Deformation Characteristics of Wrought S-816 at 1350 F.

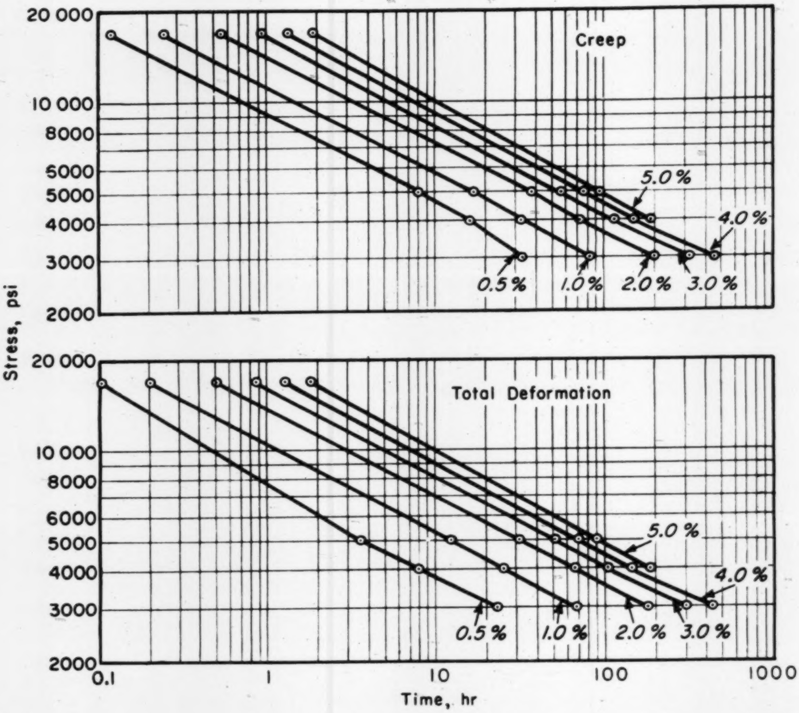

Fig. 9.—Static Compression-Creep and Total Deformation Characteristics of Wrought S-816 at 1600 F.

In addition to establishing the compression-creep characteristics of the wrought S-816 alloy, limited tension-creep tests were performed on the same lot of alloy at the 1350- and 1600-F temperature levels. These tension-creep test results are included in the time *versus* total deformation curves in Figs. 6 and 7 comparing creep behavior in tension and compression at both 1350 and 1600 F. At the 1350-F temperature level, no significant differences were noted in the tension and compression creep behaviors up to approximately 3 per cent total deformation. For the 1600-F comparison at both the 4000 and 5000 psi stresses for which correlations were made, the S-816 alloy displayed considerably less resistance to creep when exposed to the compressive stresses. It was also observed that initial deformation upon application of the load was greater for compression than for tension at this temperature. The results of the 1600-F tension and compression creep tests are further compared in Fig. 10 with tension-creep results for 0.5 and 1.0 per cent creep reported by Cross and Simmons (9). This data comparison also indicates the tendency for more rapid compression-creep than tension-creep for S-816 bar

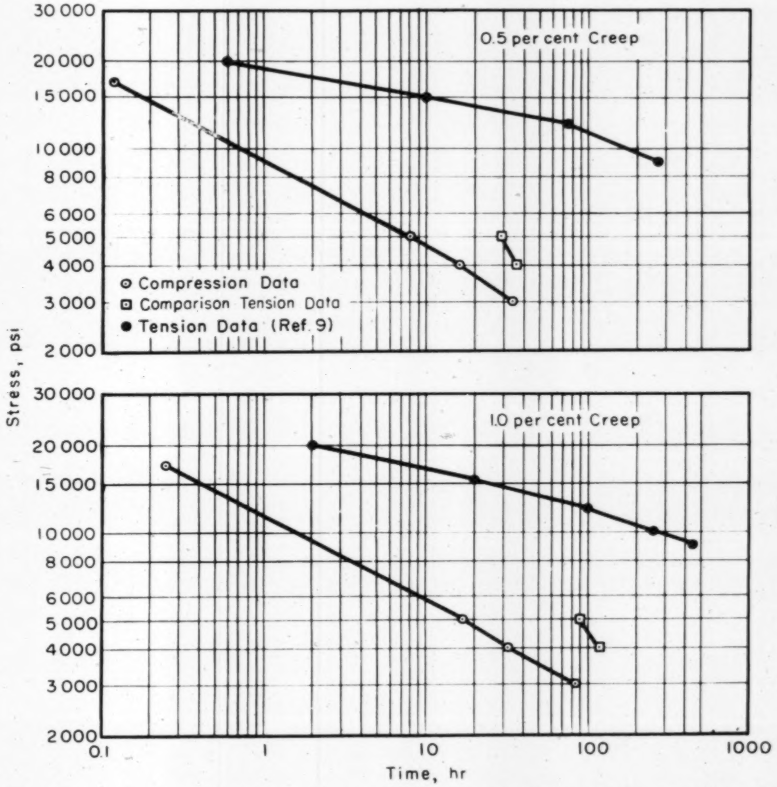

FIG. 10.—Comparison of Static Tension- and Compression-Creep Characteristics of Wrought S-816 at 1600 F.

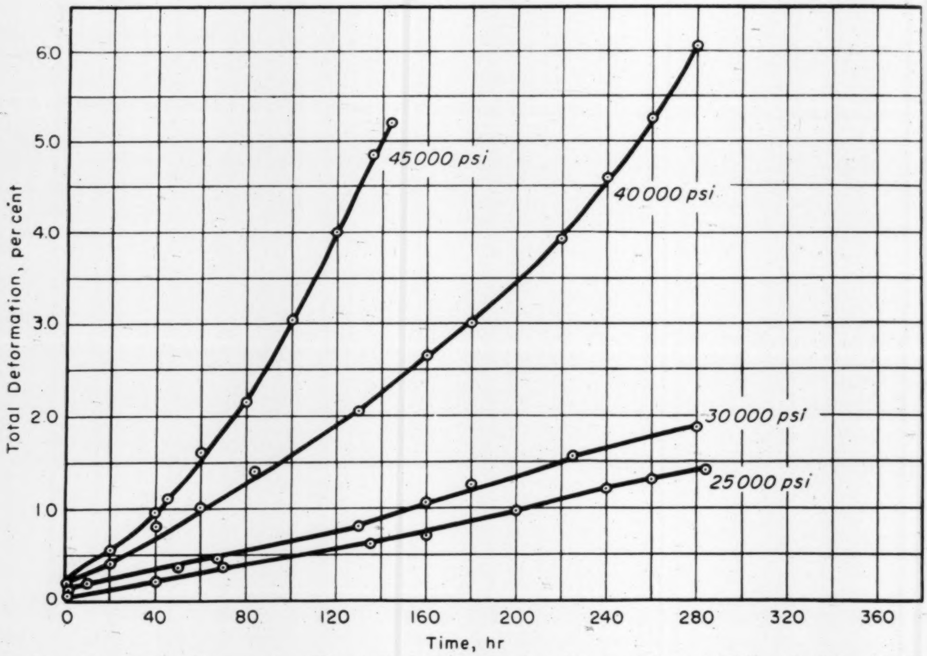

FIG. 11.—Static Compression Time - Total Deformation Characteristics of Wrought Nimonic 90 at 1350 F.

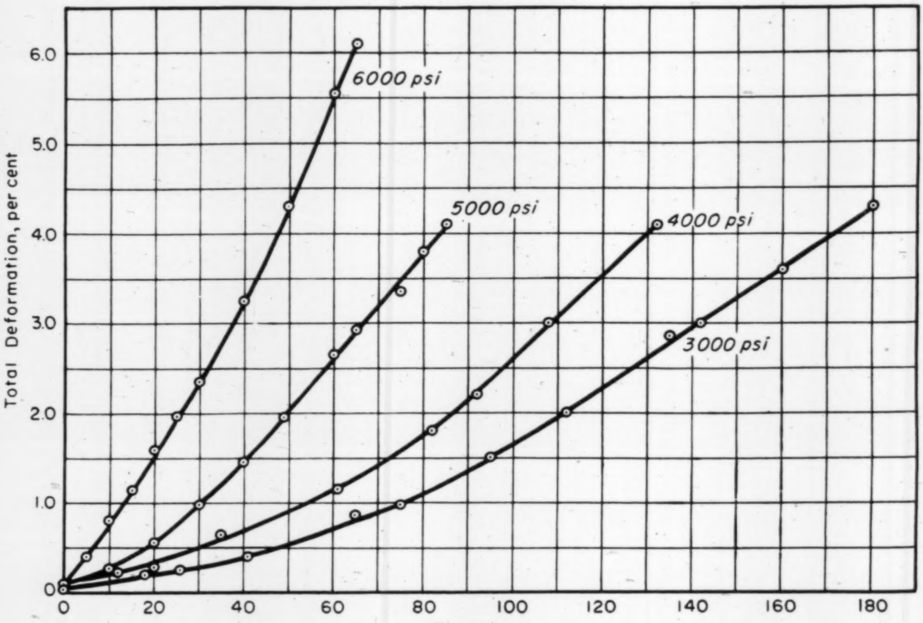

FIG. 12.—Static Compression Time - Total Deformation Characteristics of Wrought Nimonic 90 at 1600 F.

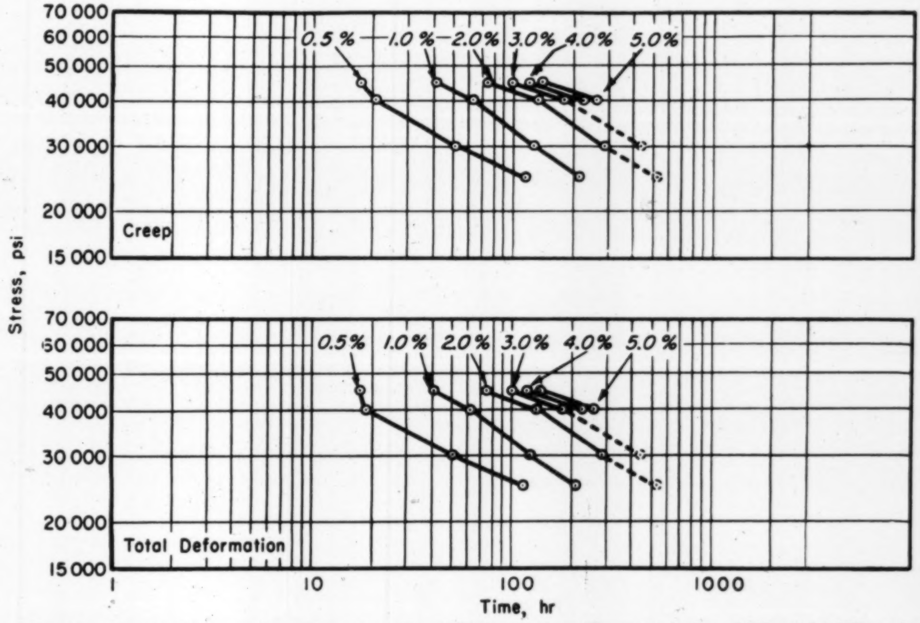

FIG. 13.—Static Compression-Creep and Total Deformation Characteristics of Wrought Nimonic 90 at 1350 F.

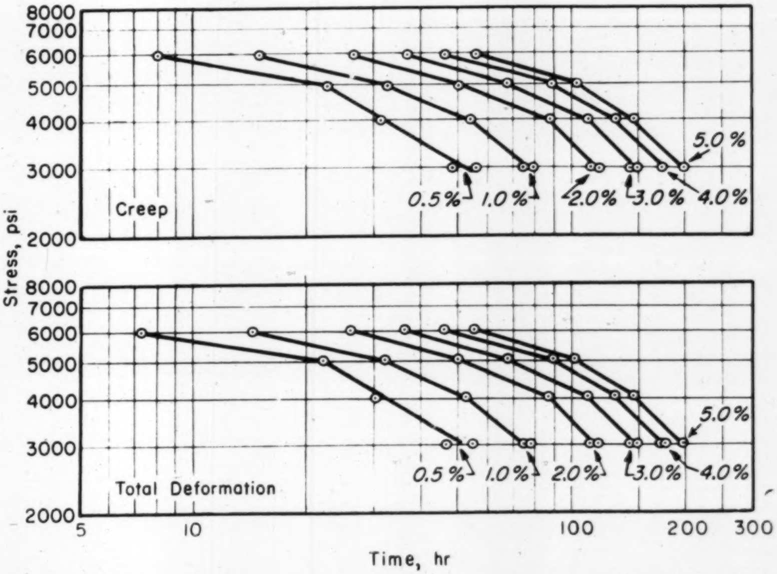

FIG. 14.—Static Compression-Creep and Total Deformation Characteristics of Wrought Nimonic 90 at 1600 F.

stock at 1600 F, although the alloy used by Cross and Simmons was pretreated by solution treating and aging at 1600 F.

Nimonic 90.—The compression-creep properties determined at 1350 and 1600 F for the hot-rolled Nimonic 90 alloy are presented graphically in Figs. 11 to 14. Correlations are also made to compare its 0.5 per cent creep behavior determined in compression with tension behavior determined by the Mond Nickel Co., Ltd., for a Nimonic 90 solution treated at 1975 F and aged at 1290 F. This correlation is presented in Fig. 15. Although the test alloys are not identical in their compositions and treatments, creep in compression was considerably faster than in tension. It is significant to note that the 1350-F compression stress-time characteristics appear to conform with the 1500-F tension stress-time characteristics for the 0.5 per cent creep strain level.

Molybdenum.—Included in the series on wrought materials are the compression-creep tests conducted on swaged, arc-cast molybdenum with protective coating. For the tests performed at 1600 F, the protective coating proved sufficiently satisfactory to permit the determination of the compression-creep characteristics of molybdenum for creep strains up to 5.0 per cent for time durations of several hundred hours. The creep results obtained are summarized in the curves of Figs. 16 and 17.

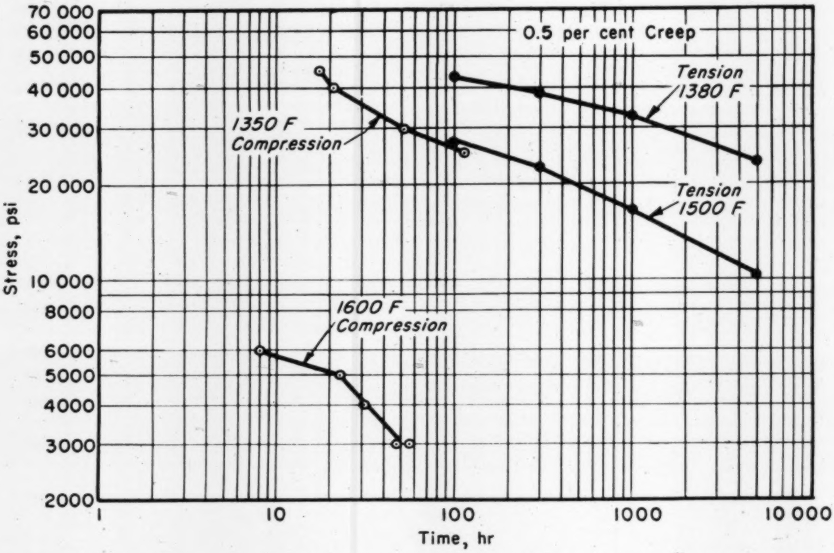

FIG. 15.—Comparison of Static Tension- and Compression-Creep Characteristics of Wrought Nimonic 90.

Because of the relatively recent introduction of molybdenum as a possible high-temperature structural metal and the difficulties associated with its elevated-temperature testing, investigations of its creep behavior have been limited, although considerable rupture information is available. There are, however, some data obtained under special test conditions which illustrate its tension-creep behavior (**10**). Because of the major differences in processing and subsequent heat treatment, together with the high-temperature

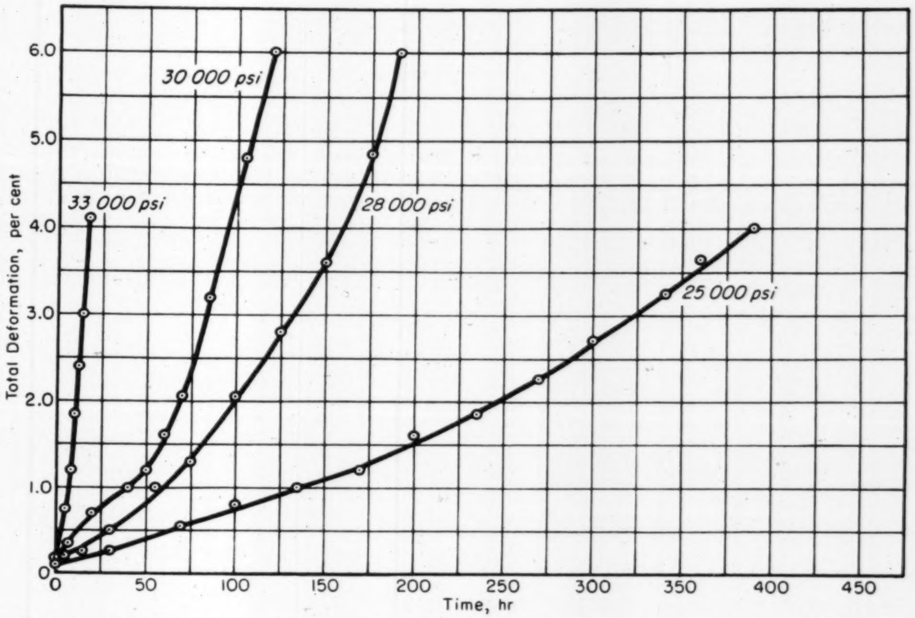

FIG. 16.—Static Compression Time - Total Deformation Characteristics of Swaged, Arc-Cast Molybdenum at 1600 F.

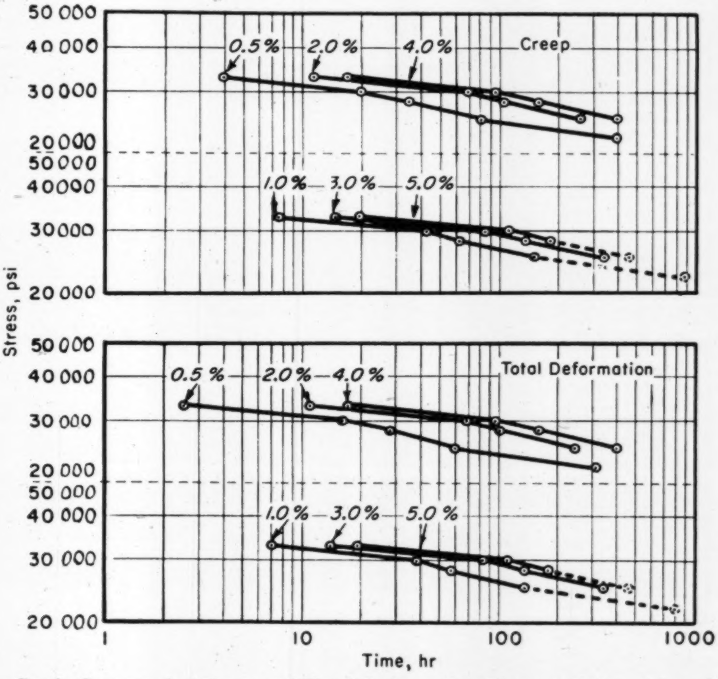

FIG. 17.—Static Compression-Creep and Total Deformation Characteristics of Swaged, Arc-Cast Molybdenum at 1600 F.

strength sensitivity of molybdenum to the processing variables, valid comparisons of the compression results obtained in this investigation cannot be made with existing tension data.

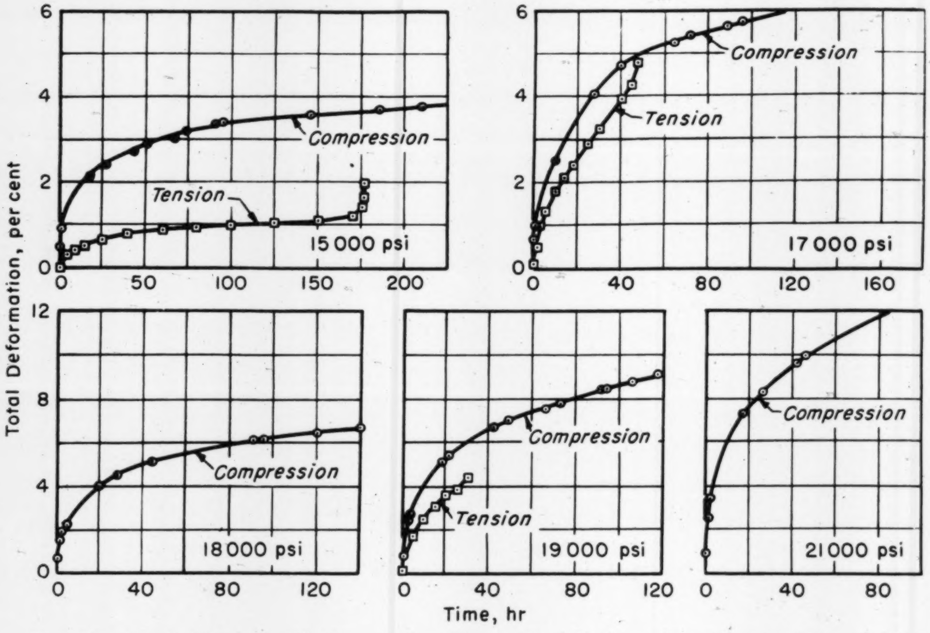

FIG. 18.—Static Tension and Compression Time - Total Deformation Characteristics of Cast Stellite 21 at 1600 F.

Cast Alloy:

Cast Stellite 21.—The 1600-F compression-creep data for cast Stellite 21 are presented in the curves of Figs. 18 and 19.

In order to compare the tension-*versus* compression-creep relationships of Haynes Stellite 21 at 1600 F, tension-creep tests were conducted at stress levels corresponding to those used in the compression-creep program. However, the test specimens employed in the tension phase of the correlation represented precision castings made from a different heat of alloy than that from which the compression specimens were cast. Comparison time-deformation curves at the specified stress levels are plotted in Fig. 18. Even though the comparisons indicate some degree of variation in tension-*versus* compression-creep behavior, particularly at the 15,000 psi stress level, such variations are not unusual for a specific set of test conditions even on the same heat of cast metal.

Cermet Compositions:

With the possibility of utilizing ceramics and metal-ceramic combinations as high-temperature stressed members where only limited deformation can be tolerated, there arises a need of evaluating these materials with respect to creep. While some success has been attained in determining stress-rupture properties, it can be assumed, in view of the meager data obtained to date, that the tension-type creep test has not proved convenient for establishing the creep behavior of these brittle materials. Because compositions have

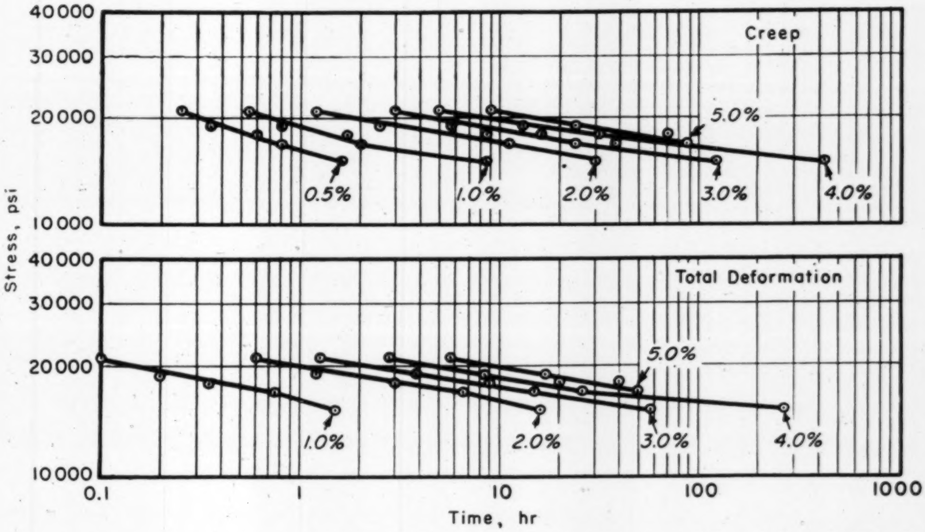

FIG. 19.—Static Compression-Creep and Total Deformation Characteristics of Cast Stellite 21 at 1600 F.

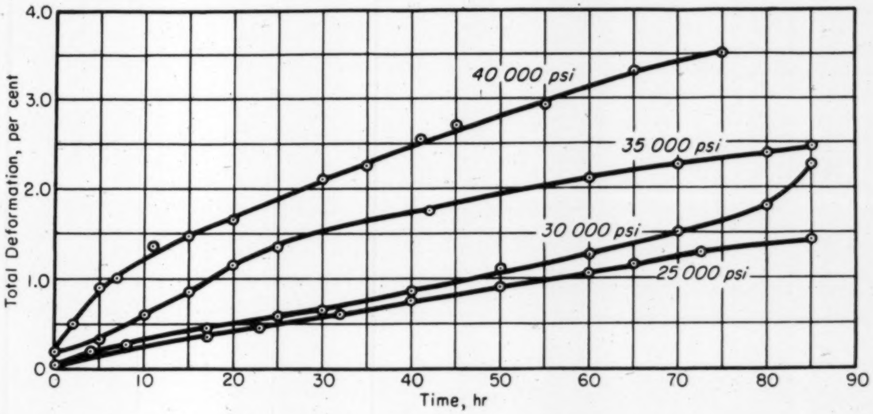

FIG. 20.—Static Compression Time - Total Deformation Characteristics of K162-B Cermet at 1800 F.

not yet been developed which operate with satisfaction under substantial tensile stress, it appears that the potentialities of the cermet compositions lie in their high compressive-strength characteristics. Recent determinations of the static mechanical properties of several titanium carbide cermets (11) indicate that materials of these types exhibit vast differences in their short-time tensile and compressive strengths; they are in the order of 3 to 10 times stronger in compression than in tension. On the basis of this observation and since cermets fall into the category of composites that depend upon binder-metal strength in tension and hard particle strength in compression, it can be ex-

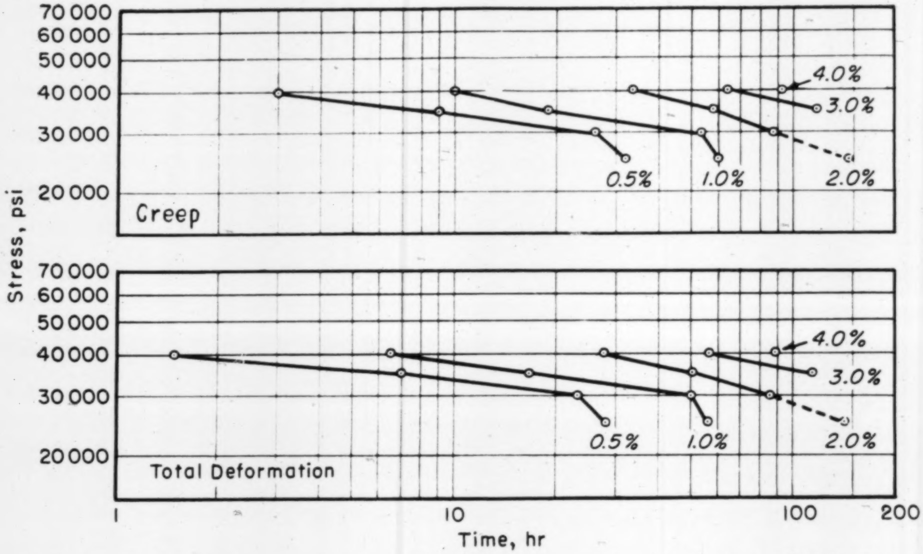

FIG. 21.—Static Compression-Creep and Total Deformation Characteristics of K162-B Cermet at 1800 F.

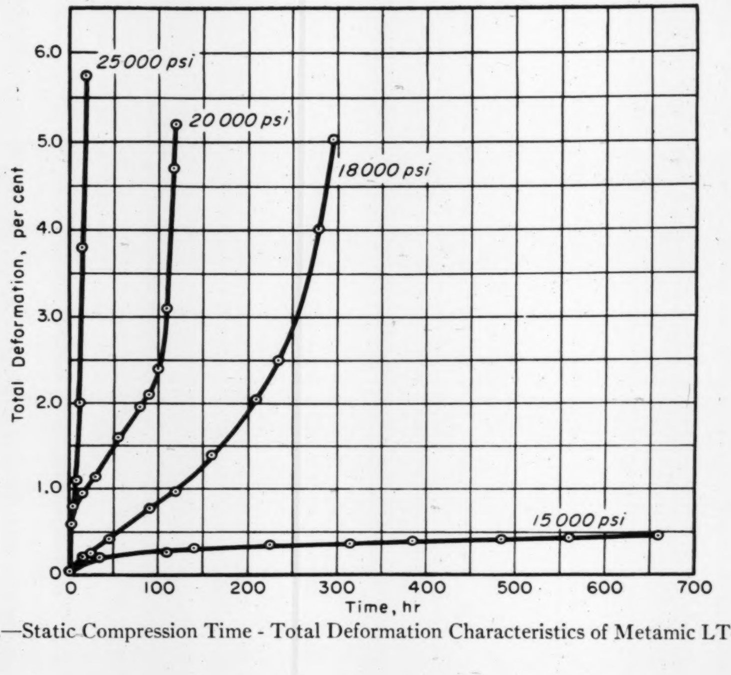

FIG. 22.—Static Compression Time - Total Deformation Characteristics of Metamic LT-1 Cermet at 1600 F.

pected that the tension-compression creep characteristics would be vastly different and probably unrelated.

K162-B Titanium Carbide.—For that portion of the investigation concerned with determining the compression-creep characteristics of refractory metal-ceramics, two composites entirely different in their make-up and manufacture were selected. One type, a metal-bonded titanium carbide (K162-B) hydrostatically pressed and sintered, was subjected to static compressive stresses at 1600 and 1800 F. The initial tests at 1600 F, for which stresses from 20,000 to 60,000 psi were applied, indicated that this metal-ceramic composite had exhibited practically no creep strain in the time span of several hundred hours. The data determined for the 1800-F series of tests are presented graphically as time - total deformation and stress-time curves of Figs. 20 and 21.

Despite the difficulties associated with the tension-creep testing of brittle metal-ceramics, Knudsen, Moreland, and Geller (12) succeeded in determining the tension-creep behaviors of several metal-bonded titanium carbide cermets. For the K162-B composition at 1800 F, they have determined the time-deformation characteristics for a static tensile stress of 10,000 psi. At this stress and temperature condition, approximately 20 hr were required to develop 1 per cent total deformation and 44 hr for 2 per cent total deformation. For these time durations under static compressive stress, by interpolating the stress-time curves in Fig. 21, it is observed that stresses of 34,700 and 37,500 psi are required to yield 1 and 2 per cent total deformation, respectively. The superiority of K162-B in compression creep immediately becomes apparent since the 1 and 2 per cent creep strengths are 3 to 4 times greater in compression than in tension on a stress basis.

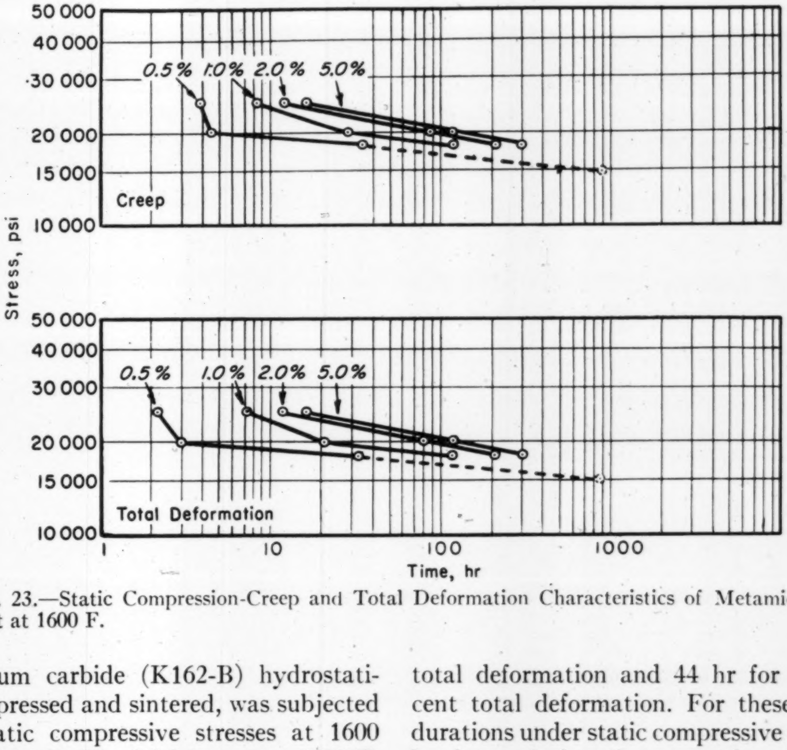

FIG. 23.—Static Compression-Creep and Total Deformation Characteristics of Metamic LT-1 Cermet at 1600 F.

Metamic LT-1.—The other metal-ceramic included in the test program consisted of a slip-cast and sintered chromium-aluminum oxide composite called Metamic LT-1. Compression-creep characteristics of this material were determined at 1600 F through the range of stresses of 15,000 to 25,000 psi. The creep results of this 1600-F series of tests are graphically presented in Fig. 22 as time - total deformation curves for the four selected static compressive stresses. A summary of the creep behavior in the form of stress-time curves for the various amounts of creep and total deformation is illustrated in Fig. 23. At the 1600-F temperature level, based on the flatness of the stress-time curves, it appears that Metamic LT-1 is sensitive to compressive stress since a small increment of stress can result in a substantial decrease in time to reach a specific amount of deformation. The time-deformation relationships bear out this observation, for at the 15,000 psi stress level less than 0.5 per cent total deformation was accrued in the time span of 600 hr, whereas at the slightly higher stress of 18,000 psi, approximately 25 hr were required to obtain the same level of total deformation. Metamic LT-1 shows a pronounced acceleration in creep after approximately 2 per cent total deformation, as illustrated in the time-deformation curves. In view of the fact that this material represents a slip-cast composite, the recorded creep strain may be the result of a combination of creep and hot compacting.

Tension-creep information for this material is not available for comparison with compression-creep data.

DISCUSSION OF RESULTS

The creep of materials subjected to compression loads at high temperatures follows a time-deformation pattern similar to that characteristic of tension loading. Depending upon the temperature and compression-stress level, various degrees of primary, secondary, and even accelerating creep are noted. Since the cross-section of a compression specimen increases during the course of its deformation, eventual deceleration of creep results due to decrease of stress at constant load, presuming failure does not occur before significant quantities of deformation are reached.

While major effort in this study to date has been devoted to the development of high-temperature compression-creep testing methods and the procurement of compression-creep data for several materials, some comment on the compression- *versus* tension-creep behavior of materials is in order. Mention has been made of the tendency for metals and alloys to display greater primary creep in compression than in tension (**2**, **3**). From the limited tension *versus* compression results obtained in this study and from data existing in the literature, it is felt that tension-compression creep comparisons should be generalized with respect to three material classifications, namely, (1) wrought metals, (2) castings, and (3) metal-ceramic composites.

In the fabrication of bar stock by preferential working in one direction, it is conceivable that residual stress patterns and elongated grain flow in the working direction could reduce resistance to compression creep in the longitudinal direction. The results obtained for S-816 and Nimonic 90 at 1600 F illustrate this effect, although this was not the case for S-816 at the lower temperature of 1350 F. According to this reasoning, castings should display similar tension- and compression-creep properties due to the absences of preferential or directional working of the material. No significant differences in the tension and compression behavior of the cast Stellite 21 was observed at 1600 F. Tension-creep properties of brittle materials would be expected to be poorer than compression properties since internal defects, cracks, and stress raisers would accelerate failure in tension but would be of minor significance in compression. Where the relatively brittle material is composed of metal-bonded hard particles as in the K162-B cermet tested, considerably higher compression-creep strength is obtained because of the mutual supporting action of the particles, whereas in tension the metal-bonding material is the controlling factor.

A summary of the compression-creep properties of all the materials investigated is listed in Table II.

TABLE II.—SUMMARY OF COMPRESSION-CREEP PROPERTIES OF TEST MATERIALS AT VARIOUS TEMPERATURES

Material	Temperature, deg Fahr	Creep Deformation, per cent	Stress, psi, for Creep Deformation in			
			10 hr	50 hr	100 hr	200 hr
Wrought S-816	1350	0.5	24 700	18 300	...	...
		1.0	31 900	23 200	19 700	...
		2.0	36 500	28 800	25 200	22 100
		5.0	...	35 200	32 200	28 000
	1600	0.5	4 700	2 600	...	...
		1.0	5 800	3 500	2 800	...
		2.0	7 300	4 600	3 700	3 000
		5.0	10 100	6 100	4 800	3 900
Wrought Nimonic 90..	1350	0.5	...	30 500	25 500	...
		1.0	...	42 300	33 000	25 500
		2.0	...	48 500	42 100	34 600
		5.0	...	...	48 400	42 000
	1600	0.5	5 700	3 100	...	...
		1.0	6 400	4 100	2 500	...
		2.0	...	5 000	3 500	1 800
		5.0	...	6 200	5 100	3 000
Swaged Molybdenum.	1600	0.5	31 400	26 500	24 300	22 800
		1.0	32 200	28 500	26 500	24 500
		2.0	33 200	30 500	28 300	25 800
		5.0	...	31 600	30 400	27 700
Cast Stellite 21......	1600	0.5	...	...	...	...
		1.0	14 800	...	...	...
		2.0	17 000	14 400	13 300	...
		5.0	21 500	17 800	16 500	...
K162-B	1800	0.5	33 800	...	...	...
		1.0	39 800	30 000	...	...
		2.0	...	36 300	28 400	24 300
Metamic LT-1.......	1600	0.5	19 200	17 800	16 900	16 200
		1.0	24 000	19 100	18 000	17 300
		2.0	25 500	21 100	19 500	18 000
		5.0	26 700	22 100	20 600	18 900

SUMMARY AND CONCLUSIONS

1. A test apparatus suitable for operating up to 1800 F has been designed and constructed to permit the evaluation of the high-temperature creep behavior of materials, both metals and metal-ceramic composites, under the influence of static compressive stresses.

2. The compression-creep characteristics, up to 5 per cent creep, have been determined for four metallic and two metal-ceramic materials in the temperature range of 1350 to 1800 F.

3. Comparison of tension-creep and compression-creep characteristics indicates that metals do not necessarily behave identically under static tension and compression stresses. The alloy S-816 in wrought bar form shows an acceleration in creep at 1600 F associated with compressive loading. Similar accelerated creep effects were observed for wrought bar Nimonic 90 in compression when compared with published tension-creep data.

4. Variations in tension-compression creep behaviors for wrought alloys are probably related to microstructural and orientation effects generated in their processing.

5. Comparisons of the tension- and compression-creep behaviors of cast Haynes Stellite 21 at 1600 F show only small differences in creep behavior associated with type of load.

6. The creep strength superiority in compression of the metal-ceramic composite K162-B suggests that creep in tension is dependent upon metal-binder characteristics and in compression upon hard particle properties.

Acknowledgment:

This investigation has been conducted under the sponsorship of the Air Research Laboratory of the Wright Air Development Center, Dayton, Ohio. Appreciation is expressed to J. P. Hirth for his cooperation in administering the program.

The authors also would like to thank W. M. Roberts and the personnel of the Structures Research Division of the National Advisory Committee for Aeronautics, Langley Field, Va., for the benefits derived from their experience in compression testing of materials.

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DISCUSSION

MR. M. J. MANJOINE.[1]—The running of a compression test involves quite a few difficulties, some of which the author has mentioned. The difficulty which is most frequently encountered is that of maintaining axiality of the load. We have found that it is difficult to maintain axiality by keeping the heads of the testing machine parallel to each other without some lateral motion perpendicular to the axis of the specimen taking place. This is especially true when the aligning joints are placed far from the heads of the test specimen.

At the Westinghouse Research Laboratories we have developed a fixture for compression tests which uses tensile loading. The fixture can be put in the conventional creep or tension machine and can be adapted to use the standard extensometers. A set-up of this fixture in a conventional lever arm creep machine is shown in the accompanying Fig. 24. Thus no special machine is necessary.

The fixture consists of two yokes, Fig. 25, which contain the compression seats and pinned tension joints. The yokes are machined so that the compression seats are parallel. The yokes, Fig. 24, fit over and guide each other to prevent lateral motion but allow free axial movement. The swivel joints, one in each yoke, are at right angles and are near the specimen ends. Thus they are very effective in reducing eccentricity of the load.

MR. L. A. YERKOVICH (*author*).—The modification to the standard tension creep testing machine for conducting compression creep tests illustrated by Mr. Manjoine appears to fulfill the basic requirements of compression creep testing. The scheme of attaching extensometers to the load-applying yokes rather than to the specimen itself is excellent

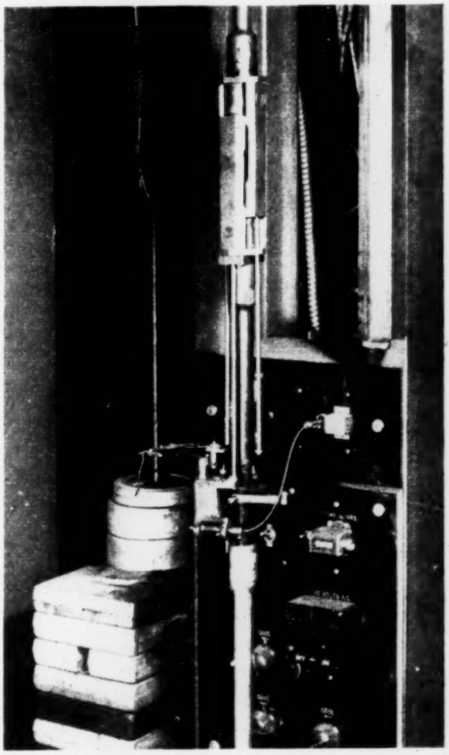

FIG. 24.—Setup of Compression Fixure and Extensometer in a Conventional Lever Arm Creep Machine.

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[1] Research Engineer, Westinghouse Electric Corp., East Pittsburgh, Pa.

since the relative displacement of the yokes is a direct measure of the strain in the specimen. However, there exists some doubt as to the validity of strain fretermined in a compression specimen when the entire specimen is used as the test section. These doubts arise from the frictional forces developed at the bearing surfaces of the specimen which restrict normal expansion during compression, thereby resulting in localized barreling and the generation of a pronounced stress gradient within the specimen. Nevertheless, within limits of stress and temperature dictated by the creep and oxidation resistance properties of the materials from which the yokes are made, Mr. Manjoine present a very useful tool for assessing materials in long-time high-temperature compression.

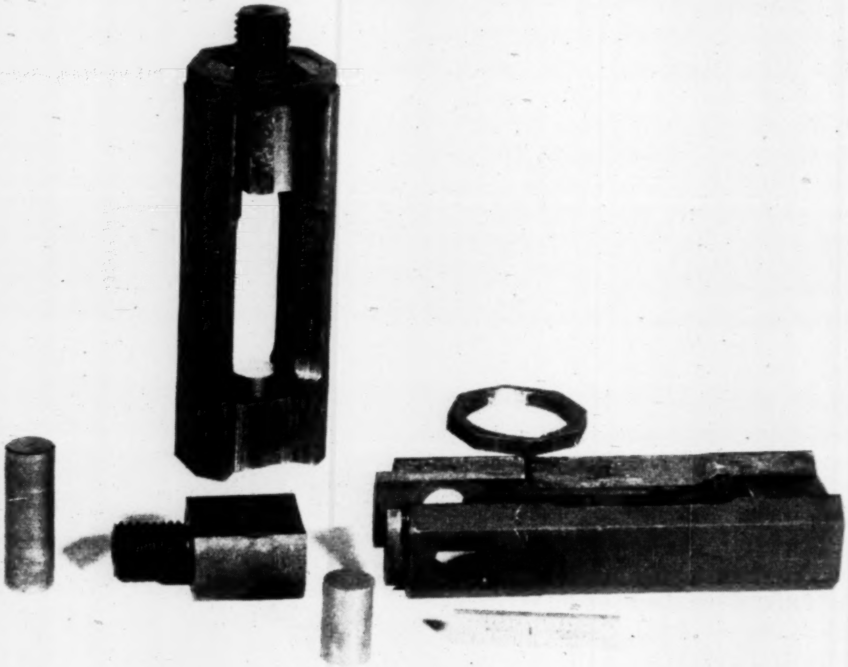

FIG. 25.—Test Specimen and Parts of Compression Fixture.

SOME THERMAL AND MECHANICAL PROPERTIES OF INCONEL AT HIGH TEMPERATURES FOR USE IN AERODYNAMIC HEATING RESEARCH*

By William J. O'Sullivan, Jr.[1]

The National Advisory Committee for Aeronautics, through its research on the design of present and future supersonic airplanes and guided missiles, has recognized the importance of the phenomenon of aerodynamic heating on the structures of aircraft and particularly on the materials of construction.

Aerodynamic heating results from the adhesion of air to the surface of the aircraft, forming a layer of retarded air called the boundary layer which envelops the aircraft. Air brought to rest in the boundary layer undergoes an increase in temperature because its kinetic energy of motion is converted into heat. The magnitude of the temperatures involved is illustrated in Fig. 1. Here is plotted the steady-state temperature attained by that part of an aircraft's skin located 2 ft from a leading edge when the boundary layer is turbulent, against the speed expressed as Mach number, that is, with the velocity of sound taken as the unit of velocity. Curves are shown for flight at sea level and at 50,000 ft altitude, for aircraft whose surfaces have emissivities of zero and unity which correspond respectively to no loss of heat by radiation and maximum possible cooling by radiation. At several times the speed of sound, the temperatures attained are seen to be readily capable of producing serious loss of strength of structural materials. This has created a demand for measurements of the mechanical properties of metals at elevated temperatures to delineate the speed range over which each may be used most advantageously, for the structure of aircraft must have the greatest strength-to-weight ratio possible.

The heat, however, does not spread itself instantly throughout the aircraft's structure. Some parts are heated and expand before others. This produces thermal stresses and panel buckling which consume part of the strength of the structure. The flow of heat through metals is governed by their specific heat, thermal conductivity, and density which combine to form the thermal diffusivity (**1, 2**).[2] These properties, together with the coefficient of thermal expansion and the elastic properties, govern the formation of thermal stresses. Hence, these thermal properties of metals must also be measured.

The rate at which heat is transferred from the boundary layer to the aircraft governs how quickly, under given flight conditions, the aircraft becomes heated. This influences the magnitude of the thermal stresses and how closely the steady-state temperature is approached in aircraft which operate at high Mach numbers for only brief intervals of time. The rate of heating requires measurement of the aerodynamic heat-transfer coefficient, which is most conveniently done by using the skin of the aircraft as a calorimeter (**3**). To do this requires precise knowledge of the specific heat of the skin material. When the ratio of radiative to aerodynamic heat transfer becomes significant, as at high temperatures and in low density air at high altitudes, the emissivity of the aircraft's surface must also be known. Because emissivity is a surface property, its value for a given metal may be varied over a large range, as by oxidation. As illustrated by Fig. 1, interest is primarily in development of high emissivity surfaces on metals because radiation is an important means of cooling high Mach number aircraft.

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* Presented at the Fifty-eighth Annual Meeting of the Society, June 26–July 1, 1955.

[1] National Advisory Committee for Aeronautics, Langley Aeronautical Laboratory, Langley Field, Va.

[2] The boldface numbers in parentheses refer to the list of references appended to this paper, see p. 763.

The National Advisory Committee for Aeronautics, in conducting research on aerodynamic heating and its structural effects on supersonic aircraft, has not only recognized that the aforementioned properties of metals must be known but also that the mathematical theory of the flow of heat through solids as thus far developed presupposes an ideal material whose thermal properties are constants (**1, 2**). Real metals usually have thermal properties that vary with temperature, possess anomalies, and not infrequently exhibit hysteresis of variable magnitude. In addition, theoretical solutions of the flow of heat in complex structures are exceedingly difficult if at all possible, even for the ideal material. Thus, the practical approach is experimental, employing models constructed so as simultaneously to fulfill the aerodynamic, thermal, and structural laws of similarity. This lessens the requirements upon the material. The necessary material need only have properties that are time invariant, that is, functions only of temperature. However, for the development of structural configurations inherently capable of withstanding aerodynamic heating, the model material should be as free as possible from anomalies in order that the results be not highly specific to the particular material employed.

In searching for such a model material, existing metallurgical data (**4**) indicated that a nickel-chromium-iron alloy of substantially the nominal composition of commercial Inconel might possess the requisite properties. Inconel, like all other industrial alloys, contains small amounts of other elements economically impractical of removal, of which carbon, through its carbide-forming properties, gave indications of being the most offensive in producing anomalies. Accordingly, measurements to high temperatures were made of the more important thermal and mechanical properties of Inconel of three levels of carbon content that more than cover the normally encountered range.

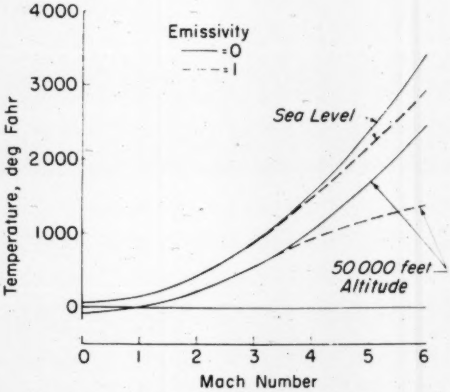

FIG. 1.—Aircraft Equilibrium Skin Temperature at 2 ft from the Leading Edge for a Turbulent Boundary Layer.

The International Nickel Co., through E. N. Skinner, gratuitously furnished the desired samples of Inconel in the form of rolled bar stock together with chemical analysis. At the NACA Langley Aeronautical Laboratory the test specimens were prepared and the tensile properties at elevated temperatures measured by G. J. Heimerl, J. E. Inge, and F. W. Schmidt. Under NACA contract, there was measured at the National Bureau of Standards the specific heat by T. N. Douglas and A. W. Harman, the thermal conductivity by H. E. Robinson and S. Katz, the coefficient of expansion by P. Hidnert, exploratory measurements of the development of an oxidized surface of high emissivity, and, as a by-product, some measurements of electrical conductivity by D. C. Ginnings.

TABLE I.—CHEMICAL COMPOSITION OF INCONELS.

Inconel Specimen	Chemical Composition, per cent									Rockwell Superficial Hardness, 15 T Scale
	Carbon	Nickel	Chromium	Iron	Manganese	Silicon	Copper	Sulfur	Total	
Low carbon	0.02	75.99	14.42	8.87	0.28	0.17	0.22	0.007	99.98	78
Medium carbon	0.07	76.45	14.96	7.89	0.26	0.19	0.15	0.007	99.98	80
High carbon	0.11	75.64	15.32	8.17	0.33	0.21	0.19	0.007	99.98	83

INCONEL SPECIMENS

The chemical compositions of the low-, medium-, and high-carbon content Inconels employed in the tests are given in Table I. The carbon contents were 0.02, 0.07, and 0.11 per cent. Also given is the average hardness of the specimens as tested in an annealed condition in order that they be in a relatively stable state with respect to intermetallic compounds and strain energy content. The annealing was performed at 2050 F, followed by cooling in quiescent air, and for each carbon content alloy the hardness is approximately the minimum attainable without inducing excessive grain growth (5).

SPECIFIC HEAT

The specific heat was determined by measuring the enthalpy, or heat content, above 32 F as a function of temperature by means of a high-precision ice calorimeter (6), fitting equations to the measurements by the method of least squares, and differentiating the equations with respect to temperature to obtain equations for the specific heat as a function of temperature.

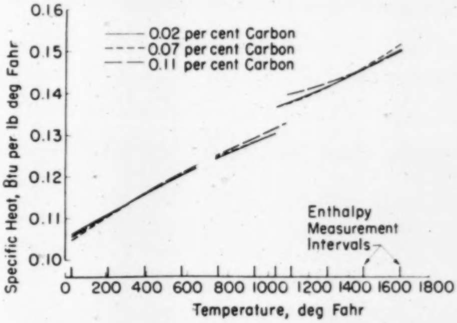

FIG. 2.—Specific Heat of Inconels of Three Carbon Contents.

In Fig. 2 are shown the curves of specific heat as functions of temperature for the three carbon content Inconels. The vertical lines on the abscissa axis represent the temperatures at which the enthalpy measurements were made. It is seen that in the vicinity of 1000 to 1100 F all three carbon content Inconels exhibit an anomaly. Repeat measurements of enthalpy above and below the anomaly were made on the 0.07 and 0.11 per cent carbon Inconel and the values found repeatable.

The influence of degree of annealing

was investigated at 1112 and 1652 F on the 0.07 per cent carbon Inconel and no effect was detected. In the vicinity of the anomaly, the enthalpy measurement intervals are not sufficiently close for the specific heat to be considered accurate.

THERMAL CONDUCTIVITY

The measurements of thermal conductivity were performed on cylindrical specimens of about 1-in. diameter having test sections about 10 in. in length. One end of the specimen was held at a constant elevated temperature by an embedded electric heater, the power input to which was measured. The opposite end was held at a constant lower temperature by a circulating liquid coolant. Seven thermocouples were attached to the specimen at equal intervals along the test section. The specimen was surrounded by a thermal guard cylinder equipped with heaters and cooling jacket so that the temperature gradient along the guard cylinder could be accurately adjusted to match that of the specimen. The space between the specimen and guard cylinder was filled with an insulation of known thermal conductivity. The heat released by the embedded electric heater was thus constrained to flow along the length of the test section of the specimen. From the measured temperature gradient and heat flux in the specimen, the thermal conductivity was determined.

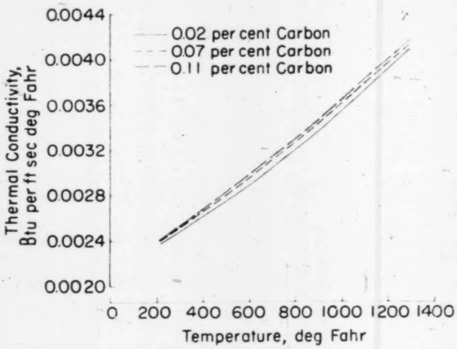

FIG. 3.—Thermal Conductivity of Inconels of Three Carbon Contents.

In Fig. 3 are plotted curves of thermal conductivity against temperature for the three carbon content Inconels tested. The curves shown were fitted to the measurements by the method of least squares, and each curve represents tests upon two specimens. For the 0.07 and 0.11 per cent carbon Inconels, the measurements are probably accurate to 5 per cent or better. For the 0.02 per cent carbon Inconel, the two specimens gave results differing by about 3 per cent, so that the average curve shown is probably accurate to about 7 per cent. The measurements give no indication of an anomaly in the vicinity of 1000 to 1100 F.

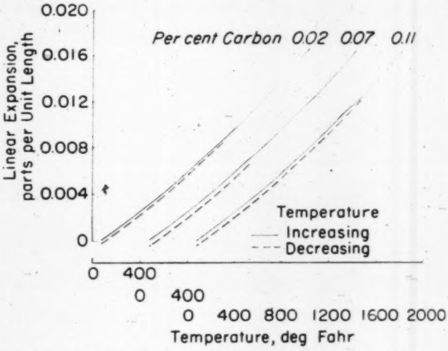

FIG. 4.—Linear Thermal Expansion of Inconel of Three Carbon Contents.

THERMAL EXPANSION

In Fig. 4 is shown the measured linear expansion from 32 F against temperature for the three carbon content Inconels. The solid curves were measured as the temperature increased and the broken curves as the temperature decreased. A distinct hysteresis is evident, and in the 0.07 and 0.11 per cent carbon Inconels the increasing temperature curves exhibit irregularity near 1400 F. On nickel-chromium-iron alloys near the composition of Inconel, previous research by Hidnert (7) has indicated that repeatable expansion characteristics may be produced by repeated heating and cooling over the temperature range. Exploratory tests on the expansion of Inconel cycled from room temperature to 1800 F at the NACA Langley Aeronautical Laboratory appear to confirm that the expansion characteristics of Inconel can be made repeatable and that the stabilized expansion curve has significantly greater slope than that of the unstabilized material.

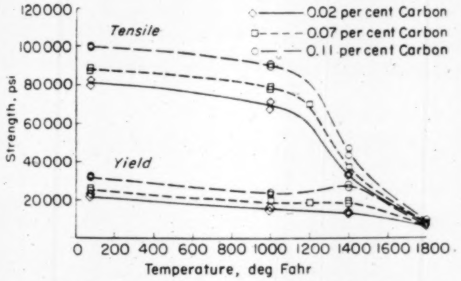

FIG. 5.—Tensile Strength and 0.2 per cent Offset Yield Strength of Inconel After $\frac{1}{2}$ hr at Temperature.

MECHANICAL PROPERTIES

There is plotted in Fig. 5 the tensile strength and the 0.2 per cent offset yield strength against temperature for the 0.02, 0.07, and 0.11 per cent carbon content Inconels as measured using $\frac{1}{4}$-in. diameter tension specimens of 1-in. gage length. The specimens were tested at temperature after being at temperature $\frac{1}{2}$ hr. The yield and tensile strengths increase with carbon content. The onset on rapid deterioration of tensile strength appears to occur at a somewhat lower temperature than that for the yield strength. The yield strength of the 0.11 per cent carbon Inconel exhibits an increase near 1400 F, a behavior frequently encountered in precipitation hardenable materials. Accurate measurements of Young's modulus of elasticity could not be obtained on the small test specimens, but the deterioration of the modulus with increase of temperature was observed to be similar to that of the tensile strength.

ELECTRICAL RESISTANCE

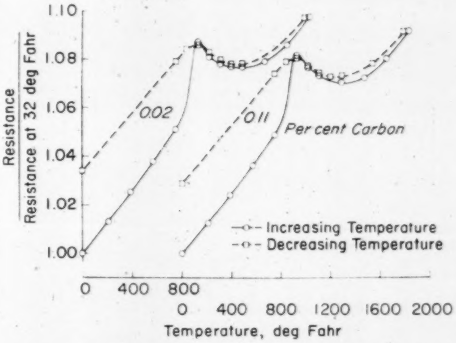

FIG. 6.—Electrical Resistance of Inconel of Two Carbon Contents.

The measured electrical resistance at temperature divided by the resistance at 32 F is plotted against temperature in Fig. 6 for the 0.02 and the 0.11 per cent carbon Inconels. The solid curves represent measurements taken with increasing temperature; the broken curves were obtained with decreasing temperature after the specimen had been cooled and reheated to the highest temperature shown. The measurements were made on 2-ft lengths of 0.032-in. diameter wire annealed at 2012 F for 9 min and cooled in quiescent air. In the region near 900 F, the resistance with decreasing temperature was observed to require about 1 hr to reach the nearly steady value shown. The resistance measurements were made in anticipation of employing resistance as a measure of temperature in emissivity measurements by the electrically heated wire-in-vacuum method. The anomalous behavior of the electrical resistance, although precluding emissivity measurements in the anticipated manner, serves to substantiate the existence of the anomaly observed in the specific heat measurements and detected in the expansion measurements.

EMISSIVITY

An attempt has been made to obtain measurements of the emissivity of oxidized Inconel by modifying the heated wire-in-vacuum method so that the temperature of the heated wire specimen is measured by means of a minute thermocouple attached to it rather than by the change of electrical resistance of the specimen wire. In Fig. 7 is shown tentative values of emissivity against temperature obtained by this modified technique for the 0.02 and 0.07 per cent carbon Inconels as measured upon 0.032-in. diameter wire specimens that were cleaned by pickling and then oxidized in air by heating to 2050 F for 10 to 15 min. The oxidized surface thus produced is of a bluish-black color, quite thin, very adherent, resistant to mild abrasion, and as smooth as the metal surface before oxidation. The oxidation process has also been developed for application to large surfaces and gives consistent results. In developing the process it was noted that departures from the proper procedure gave erratic results, frequently producing a greenish oxide that was not adherent, or what appeared to be a mixture of the greenish and bluish-black oxide. In view of the modification of the emissivity measurement technique, the effects of variation in oxidation procedure upon the type of oxidized surface produced, and the lack of repeat measurements of the emissivity, the values presented in Fig. 7 must be considered tentative. In particular, the influence of time at oxidizing temperature, which presumably governs the thickness of the oxidized layer, requires investigation to determine the minimum thickness of oxidized layer needed to ensure that the low emissivity of the clean metal has been entirely replaced by that of the oxidized surface. The measurements, however, appear consistent with those reported by De-Corso and Coit who employed a different method (**8**).

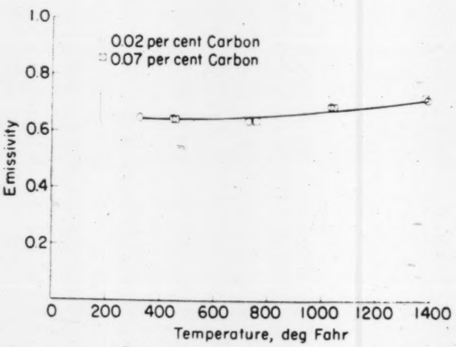

FIG. 7.—Emissivity of Two Inconels Oxidized at 2050 F in Air for 10 to 15 min.

CONCLUSIONS

This investigation of the high-temperature thermal and mechanical properties of Inconel of three levels of carbon content provides the major items of technical information required for the employment of this material in the investigation of aerodynamic heating and its effects upon the structures of supersonic airplanes and guided missiles. The measurements will probably be of use in other technical fields involving heat transfer and structures subject to elevated temperatures. Although Inconel is not ideally suited to these research uses by virtue of the anomaly that it has been found to possess, it is at present the only material which simultaneously fulfills the requirements that its properties be adequately known, that it be capable of withstanding high temperatures, that it be commercially available in standard structural shapes at reasonable cost, and that it be readily susceptible to fabrication by ordinary shop methods.

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(3) Leo T. Chauvin and Carlos A. deMoraes, "Correlation of Supersonic Convective Heat-Transfer Coefficients from Measurements of the Skin Temperature of a Parabolic Body of Revolution (NACA RM-10)," *RM L51A18*, Nat. Advisory Comm. Aeronautics (1951).

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(6) D. C. Ginnings, T. B. Douglas, and A. F. Ball, "Heat Capacity of Sodium Between 0 and 900 C, the Triple Point and Heat of Fusion," *Journal of Research*, Nat. Bureau Standards, Vol. 45, No. 1, July, 1950, pp. 23–33. (*RP 2110.*)

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DISCUSSION

MR. W. F. BROWN, JR.[1]—I should like to ask whether the discontinuity observed in the specific heat curves persists if a test on the same sample is repeated.

MR. W. J. O'SULLIVAN, JR. (*author*).—Repeat measurements were made of the enthalpy at temperatures above and below the anomaly. It was found that the anomaly was repeatable in all three carbon content inconels.

MR. S. S. MANSON.[1]—The author has determined thermal diffusivity by direct measurement of specific heat, density, and conductivity. Thermal diffusivity can, however, be determined indirectly by methods involving fewer measurements, for example, by temperature distribution determinations in bodies of regular geometrical shape. Has any attempt been made at this type of determination of thermal diffusivity?

MR. O'SULLIVAN.—The components of the thermal diffusivity were measured rather than measuring the thermal diffusivity directly because the components are required in many important cases. For example, the specific heat is required in the method of measuring the aerodynamic heat transfer coefficient as described in reference 3 of the paper.

MR. E. N. SKINNER.[2]—I should like to comment briefly as to the probable cause of the anomalous behavior of Inconel as reported by the author. It is believed that the effect noted may be attributed to the formation of an ordered structure based upon the compound Ni_3Cr. From electrical resistivity, specific heat, and instantaneous expansion data obtained for alloys of related compositions, it appears that the temperature of ordering is approximately 545 C (1013 F). While the Inconel composition, with its few per cent of contained iron, is not optimum for forming a wholly ordered structure, it appears that as the iron content is increased at the expense of the nickel, the anomaly becomes diminished in magnitude and probably would disappear entirely at a nickel content in the vicinity of 40 per cent. The implication is that it should be possible to obtain an alloy having a high level of heat resistance yet devoid of ordering or phase change which would interfere with the consistent variation of certain physical properties with temperature.

In passing, it is rather striking that the thermal conductivity curves shown for Inconel give no evidence of a discontinuity corresponding to the order-disorder transformation. We have always felt that the thermal conductivity, like the electrical resistivity, is a fairly sensitive indicator of any atomic rearrangement that may have taken place.

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[2] International Nickel Co., New York, N. Y.

AN INVESTIGATION OF THE 21 PER CENT CHROMIUM - 10 PER CENT NICKEL HEAT-RESISTANT CASTING ALLOY*

By R. J. Mangone,[1] D. D. Burgan,[2] and A. M. Hall[1]

Synopsis

An investigation was made of the effect of composition on the microstructure and mechanical properties of the 21 per cent chromium – 10 per cent nickel heat-resistant casting alloy. The composition variables studied included nickel, chromium, carbon, and nitrogen.

Though essentially austenitic, the alloy can contain ferrite or sigma under certain circumstances. The probability that ferrite can be formed is increased when the chromium content is high and the nickel content or the carbon content low. A formula relating austenite-ferrite balance to composition is proposed. Evidence suggesting that ferrite-containing compositions are susceptible to sigma formation is given. Excess carbon is disposed as eutectic carbides; secondary carbides can be precipitated at intermediate temperatures such as 1400 to 1500 F. Agglomeration and spheroidization of carbides occur at temperatures of 1900 F and above.

Data are given on room-temperature and short-time elevated-temperature tensile properties. Stress-rupture properties at 1200, 1400, and 1600 F are given. Carbon was shown to be a potent strengthener. Some data are included which support field experience that this alloy has high-temperature strength properties comparable with those of the 26 per cent chromium - 12 per cent nickel casting alloy.

Excellent resistance to thermal-fatigue cracking was observed. Improvements in this property were made when the excess carbides were spheroidized by a pretreatment at 1900 F. The average linear coefficient of thermal expansion between 80 and 1600 F was found to be about 10.5×10^{-6} in. per in. per deg Fahr.

Recent studies by members of the alloy casting industry have indicated that the 21 per cent chromium - 10 per cent nickel heat-resistant casting alloy carrying the Alloy Casting Inst.'s designation HF has mechanical properties that are competitive in the temperature range of 1200 to 1600 F with those of other alloys containing substantially greater amounts of nickel and chromium. A thorough investigation of this alloy has been reported by Avery, Wilks, and Fellows (**1**).[3] However, to increase the breadth of industrial application of this alloy, the Alloy Casting Inst. (ACI) considered it advisable to obtain additional information on the mechanical properties of the material at elevated temperatures and accordingly instituted a program at Battelle Memorial Inst. directed toward this objective.

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* Presented at the Fifty-eighth Annual Meeting of the Society, June 26–July 1, 1955.

[1] Principal Metallurgist and Chief, respectively, alloy Development Division, Battelle Memorial Inst., Columbus, Ohio.

[2] Research Metallurgist, Electric Steel Foundry Co., Portland, Ore. Formerly, Battelle Memorial Inst.

[3] The boldface numbers in parentheses refer to the list of references appended to this paper, see p. 792.

The ACI composition specification for the HF alloy, as revised in the light of some of the findings reported here, is as follows:

	Per cent
Carbon	0.20 to 0.40
Manganese	2.00 max
Silicon	2.00 max
Phosphorus	0.04 max
Sulfur	0.04 max
Chromium	19 to 23
Nickel	9 to 12

The HF alloy occupies an area in the iron-chromium-nickel system at or near the junction of the boundaries of several phase fields. It is therefore possible for the alloy to possess microstructures differing from each other in a number of respects, depending upon the proportions of nickel, chromium, and other influential elements present, as well as on the heat treatment. The alloy could contain ferrite, or sigma, or ferrite and sigma, in addition to austenite. Such variations in microstructure would be expected to influence mechanical properties materially.

The region occupied by the HF alloy in the iron-chromium-nickel ternary system is not far from that of the HH alloy (the 26 per cent chromium - 12 per cent nickel heat-resistant casting alloy). In a study of the HH alloy, it was found that variations in composition would make the alloy partially ferritic, thereby adversely affecting its high-temperature mechanical properties (2). In addition, under certain conditions, sigma could be formed in the alloy. These findings lent added support to the supposition that somewhat similar microstructural variations, with attendant variations in properties, might be found in the HF alloy.

Accordingly, in this investigation of the mechanical properties of the HF alloy, the influences of composition, heat treatment, and microstructure were emphasized.

TABLE I.—CHEMICAL COMPOSITION OF TEST MATERIALS.

Heat	Composition, per cent					
	Carbon	Chromium	Nickel	Silicon	Manganese	Nitrogen
AAK	0.33	18.34	12.11	1.00	0.78	0.100
AAL	0.33	18.80	8.31	1.10	0.78	0.108
AAM	0.33	23.28	12.26	1.02	0.83	0.114
AAN	0.31	23.60	8.20	1.00	0.75	0.113
AAO	0.25	21.43	10.19	0.99	0.82	0.118
AAO-1	0.22	20.40	10.10	1.00	0.80	0.093
AAP	0.43	20.76	10.09	0.93	0.79	0.101
AAQ	0.31	20.60	10.20	0.92	0.77	0.096
AAR	0.32	20.80	10.13	0.96	0.81	0.175
AAS-1	0.12	19.20	10.60	0.98	0.82	0.096
AAW	0.34	20.10	10.20	1.02	0.77	0.039

TEST MATERIALS

The chemical compositions of the test materials used in this study are given in Table I. Each heat was melted in a magnesia-lined high-frequency induction furnace using virgin melting stock. All heats were 350 lb.

Heat AAQ, containing mean amounts of the alloying elements in accordance with the ACI specification, was used as the control heat in making comparisons among results. Four of the heats, AAK, AAL, AAM, and AAN, were intended to represent material containing maximum and minimum amounts of chromium and nickel, as designated by the HF alloy specification. At the time this research was begun, the minimum nickel content specified was 8.0 per cent. Since then, as will be discussed later, it has been raised to 9.0 per cent. These four heats contained mean amounts of the other elements under study. Heats AAO, AAO-1, AAS-1, AAQ, and AAP constituted a variable carbon series, with all other elements held at their normal value. Heat AAS-1 was intentionally made with a carbon content well below the specification limit. It therefore cannot be classified as an HF alloy. Heats AAR, AAQ, and AAN form a similar series in which the variable is the nitrogen content.

Part of each heat was poured into dry-sand keel-block-type molds rounded at the bottom. The keel blocks were 5 in. high by 9 in. long and tapered from $1\frac{1}{2}$ in. wide at the top to 1 in. wide at the bottom radius. One tension bar, with 0.505-in. diameter and 2-in. gage length, was machined from each casting.

The balance of each heat was poured into skin-dried green sand molds from each of which two disk-shaped specimens $\frac{3}{8}$ in. thick by 4 in. in diameter were machined for thermal-fatigue testing. The specimen used for evaluating thermal-fatigue properties is illustrated in Fig. 1.

METALLOGRAPHY

The matrix of the HF alloy is austenite. The alloy also contains carbides and, in addition, has been observed to contain ferrite, sigma, and a lamellar constituent, depending on composition and heat treatment.

The test materials described in the preceding section were examined in the as-cast condition, as well as after aging 24 and 48 hr at 1400 and 1600 F. In addition, they were examined after aging 1700 and 3000 hr at both 1400 and 1500 F. The materials were also examined after heating 6 and 12 hr at 1900 F and 2 hr at 2150 F, followed by water quenching.

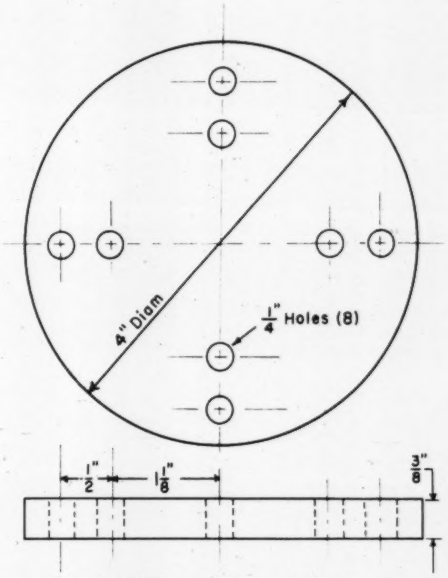


Fig. 1.—Thermal-Fatigue Specimen.

Influence of Carbon:

The effect of carbon content on the microstructure of the experimental HF alloy heats was found to be similar to that which has been reported for other cast, heat-resistant alloys of the iron-chromium-nickel type. Carbon in excess of the amount capable of being held in solution in the austenite at solidification temperatures took the form of massive, primary, eutectic carbides, or perhaps carbonitrides, in the interdendritic areas of the as-cast material (see Fig. 6(*b*)).

Aging the alloys at 1400 to 1600 F caused secondary carbides to precipitate. The carbides were most numerous in, and adjacent to, the interdendritic areas. The extent to which the precipitate extended into the austenite grains from the interdendritic areas seemed to be a function of carbon content primarily and of aging time and temperature to a lesser degree. The pattern of secondary carbide precipitation without doubt reflected microsegregation of the carbon retained in the austenite during solidification. The precipitation of secondary carbides on aging at 1400 F is illustrated in Fig. 2. A tendency for coarser secondary carbides to form at 1600 F othei than 1400 F was noted.

Whereas 24- and 48-hr aging periods at 1400 and 1500 F resulted in the precipitation of multitudes of fine, dispersed carbides, aging for 3000 hr at these temperatures resulted in the formation of needles of carbide along crystallographic planes. The needles tended to be coarser after 1500-F treatment than after 1400-F treatment. It can be speculated that the process involved in the formation of the

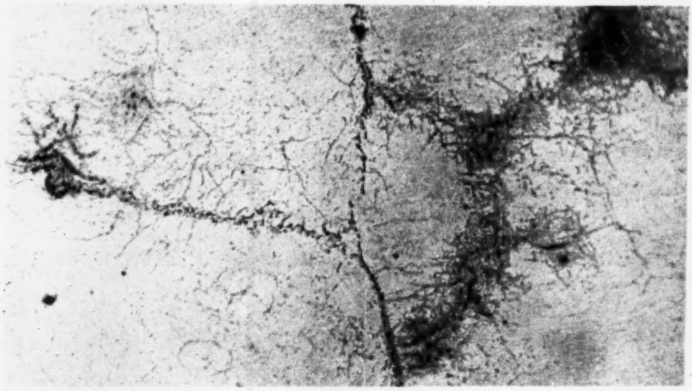


FIG. 2.—Microstructure of Heat AAP After Aging at 1400 F for 24 hr. Carbon content: 0.43 per cent. Etched with oxalic acid. (× 500.)

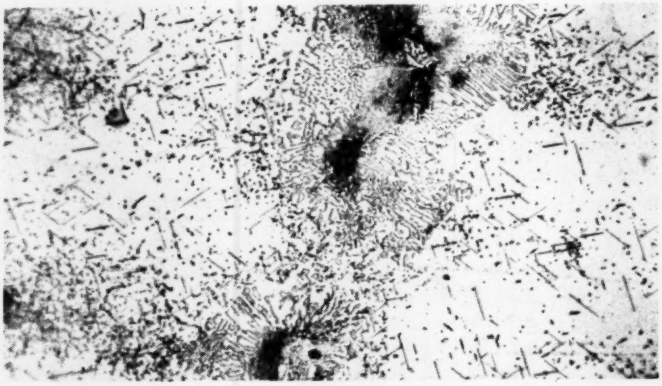
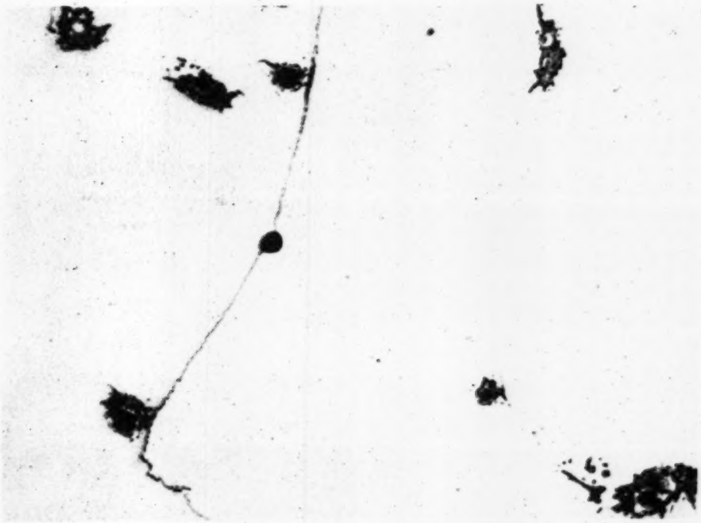
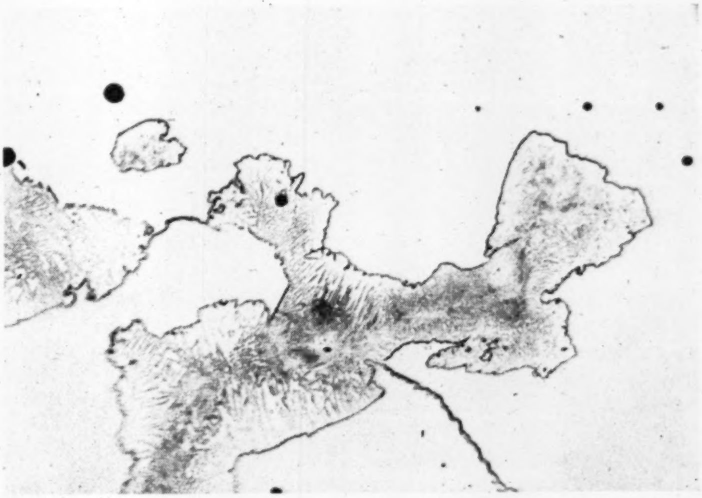


FIG. 3.—Microstructure of Heat AAP After Aging at 1400 F for 3000 hr. Carbon content: 0.43 per cent. Etched with mixed acids. (× 500.)



(*a*) Heat AAK—chromium content: 18.34 per cent; carbon content: 0.33 per cent.

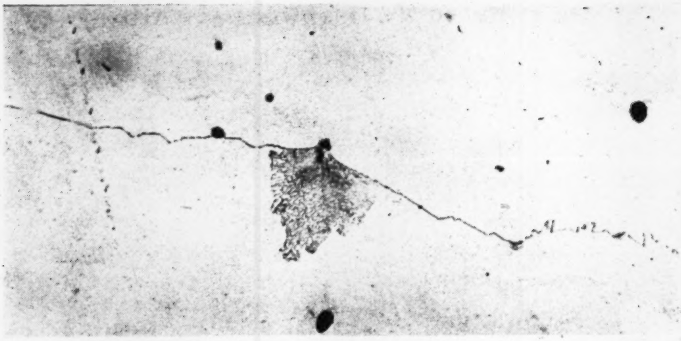


(*b*) Heat AAM—chromium content: 23.28 per cent; carbon conten:t 0.33 per cent. Note large amount of lamellar constituent.

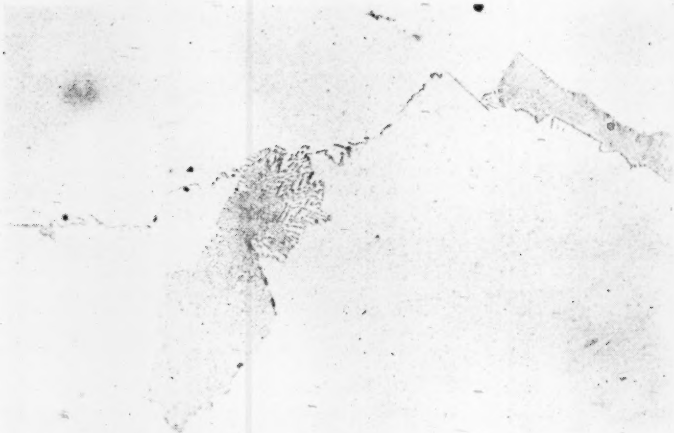
FIG. 4.—Microstructures of (*a*) Low-Chromium-Content and (*b*) High-Chromium-Content HF Alloy Heats, As Cast, Containing Approximately 12 per cent Nickel. Etched with oxalic acid. (× 500.)

needles was first the precipitation of fine carbide particles, followed by their gradual resolution and reprecipitation along major crystallographic planes with the ultimate development of needle-like forms. The effect of the long-time aging treatment is shown in Fig. 3.

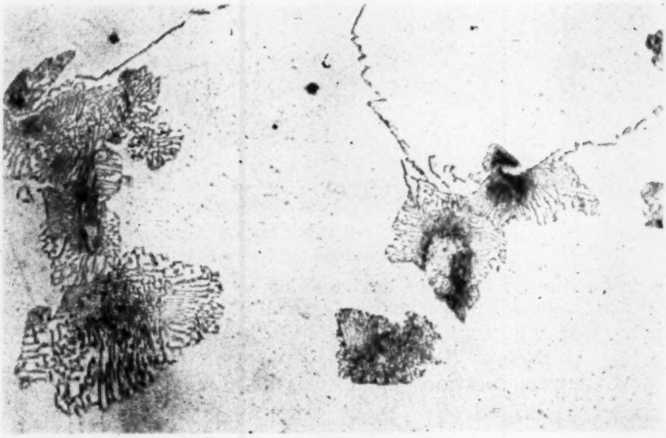
Few and much coarser carbides were observed in samples heated at 1900 F than at the lower temperatures just dis-



(*a*) Heat AAO-1—carbon content: 0.22 per cent. Note relatively small amount of lamellar constituent.

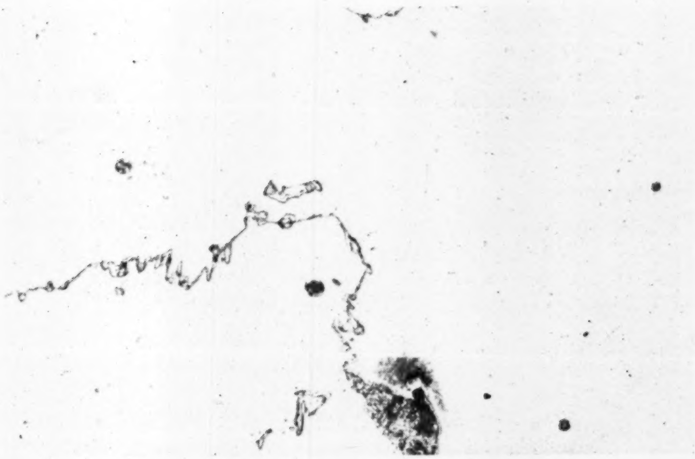


(*b*) Heat AAQ—carbon content: 0.31 per cent.

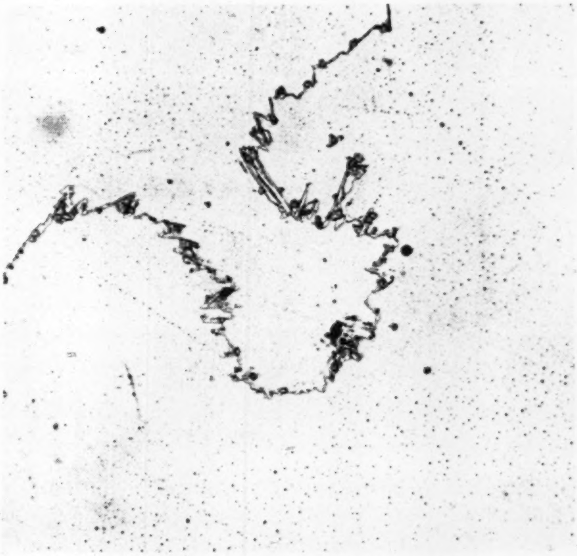


(*c*) Heat AAP—carbon content: 0.43 per cent. Note relatively large amount of lamellar constituent.

FIG. 5.—Microstructures of (*a*) Low-Carbon-Content, (*b*) Intermediate-Carbon-Content, and (*c*) High-Carbon-Content HF Alloy Heats, As Cast. Etched with modified aqua regia. (× 500.)



(*a*) Heat AAW—nitrogen content: 0.039 per cent.



(*b*) Heat AAR—nitrogen content: 0.175 per cent.

Fig. 6.—Microstructures of (*a*) Low-Nitrogen-Content and (*b*) High-Nitrogen-Content HF Alloy Heats, As-Cast. Etched with modified aqua regia. (× 500.)

cussed. This was probably the result of the processes of coalescence and spheroidization going on at this temperature, in addition to some precipitation. At 2150 F, the solubility of carbon in austenite was so great that no carbides other than the massive eutectic carbides, or carbonitrides, were observed. Furthermore, considerable coalescence and spheroidization of the primary carbides had occurred.

Lamellar Constituent:

An interesting characteristic of the heats studied was their tendency to form a lamellar or "pearlitic" constituent in some of the interdendritic areas. Avery, Wilks, and Fellows (1) also noted a lamellar constituent in heats of this type of alloy. They found that this constituent was nonmagnetic and that the quantity in which it occurred was influenced by the nitrogen content of the alloy. They suggested that it may consist of alternate plates of austenite and a complex carbonitride.

Metallographic examination of the experimental heats used in the present study suggested that, among the fully austenitic materials, there was a tendency for more of the lamellar constituent to be present in the heats of higher chromium content than in those of lower chromium content (Fig. 4). In addition, as shown in Fig. 5, there seemed to be a tendency for more of the lamellar constituent to be present in fully austenitic material as the carbon content was increased, all other factors being constant. The partially ferritic heat, AAN, seemed to be free of the lamellar constituent.

A relationship between the presence of the lamellar constituent and the nitrogen content could not be confirmed. Both the high-nitrogen and the low-nitrogen heats, AAR and AAW, respectively, appeared to contain less of the lamellar constituent than did the control heat, AAQ, which contained an intermediate amount of nitrogen (see Fig. 6).

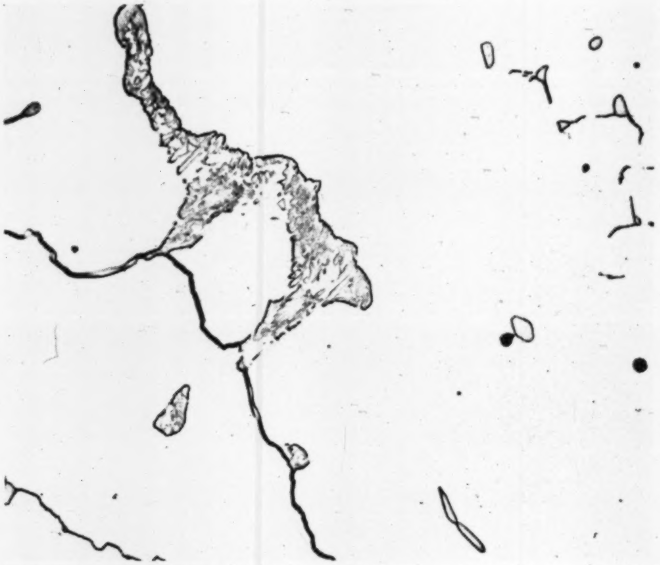


FIG. 7.—Microstructure of Heat AAN (23.6 per cent Chromium, 8.2 per cent Nickel) in the As-Cast Condition.

Ferrite is visible in the upper right-hand portion of this field. Etched with oxalic acid (× 500).

Tests made on specimens containing substantial amounts of the lamellar constituent confirmed the fact that it is nonmagnetic. Aging at 1400 and 1500 F for 3000 hr did not alter the appearance of the lamellar constituent.

In summary, the observations made in this investigation tended to confirm a relationship between the appearance of the lamellar phase and the chromium and carbon contents of the materials. However, no light was cast on the role of nitrogen in the formation of the lamellar phase.

Ferrite Formation:

Upon metallographic examination, ferrite was found in one of the eleven experimental materials in the as-cast condition. This was heat AAN, which contained the highest percentage of chromium (23.60 per cent) and the lowest percentage of nickel (8.20 per cent), together with normal amounts of the other elements under study. The ferrite observed in heat AAN is shown in Fig. 7. In the case of two other heats, AAL and AAS-1, magnetic permeability tests gave indications of the presence of ferrite in the as-cast samples. However, the quantities were too small to be observed with the microscope. Heat AAL was low in nickel content, and heat AAS-1 was very low in carbon content. The magnetic permeabilities of the test materials are given in Table II.

Magnetic permeability determinations were also made on test specimens which had been variously heat treated—aged 48 hr at 1400 F, aged 48 hr at 1600 F, and heated 6 hr at 1900 F. In four cases, heats AAL, AAN, AAO, and AAS-1, the 48-hr treatment at 1400 F increased the magnetic permeability. From this it can be assumed that the amount of ferrite in the structure had increased, presumably by precipitation from the austenite matrix. On the other hand, the 48-hr treatment at 1600 F caused the magnetic permeability of heat AAN to drop to 1.015 mμ, indicating a reduction in the amount of ferrite present. At the same time, this treatment caused the permeability of heats AAO and AAS-1 to fall to 1.005 mμ, indicating that the amount of ferrite present was substantially zero. The treatment did not affect the other test materials. Ferrite was retained only in heat AAN after the 1900 F treatment, according to permeability indications.

It was therefore evident that ferrite could form in the materials under study, depending on the composition, especially when nickel or carbon was low. Furthermore, its formation could be influenced by heat treatment. The effect of heat treatment is discussed further in the section on Sigma-Phase Formation.

Since, as indicated earlier, the HF alloy is somewhat similar to the HH alloy with regard to composition, it is not un-

TABLE II.—MAGNETIC PERMEABILITIES OF TEST MATERIALS.

Heat	Structure[a]	As-Cast	Magnetic Permeability, mμ[b]		
			After 48 hr at 1400 F	After 48 hr at 1600 F	After 6 hr at 1900 F
AAK	A + C	1.005	1.005	1.005	1.005
AAL	A + C + F[c]	1.015	1.075	1.010	1.005
AAM	A + C	1.005	1.005	1.005	1.005
AAN	A + C + F	1.060	1.195	1.015	1.015
AAO	A + C	1.005	1.010	1.005	1.005
AAO-1	A + C	1.005	1.005	1.005	1.005
AAP	A + C	1.005	1.005	1.005	1.005
AAQ	A + C	1.005	1.005	1.005	1.005
AAR	A + C	1.005	1.005	1.005	1.005
AAS-1	A + C + F[c]	1.015	1.040	1.005	1.005
AAW	A + C	1.005	1.005	1.005	1.005

[a] A = austenite, C = carbides, F = ferrite.
[b] The field strength used was 30 gauss.
[c] Assumed from the permeability result.

reasonable to postulate that some similarity may exist between the two with respect to the influence of composition on microstructure. Therefore, it seemed in order to review the findings of Gow and Harder (2) with regard to microstructural balance in the HH alloy with the thought that it may be useful in considering the HF alloy. Gow and Harder found that for commercial grades of HH alloy the boundary between fully austenitic and partially ferritic compositions could be defined by the equation:

$$\frac{\% \text{ Cr} - (16 \times \% \text{ C})}{\% \, Ni} = 1.7$$

In effect, this means that if the ratio between chromium in solid solution and nickel is less than 1.7, the composition will be entirely austenitic whereas, if it is greater than 1.7, the compositions will be partially ferritic. This value has been called the ratio factor (R.F.).

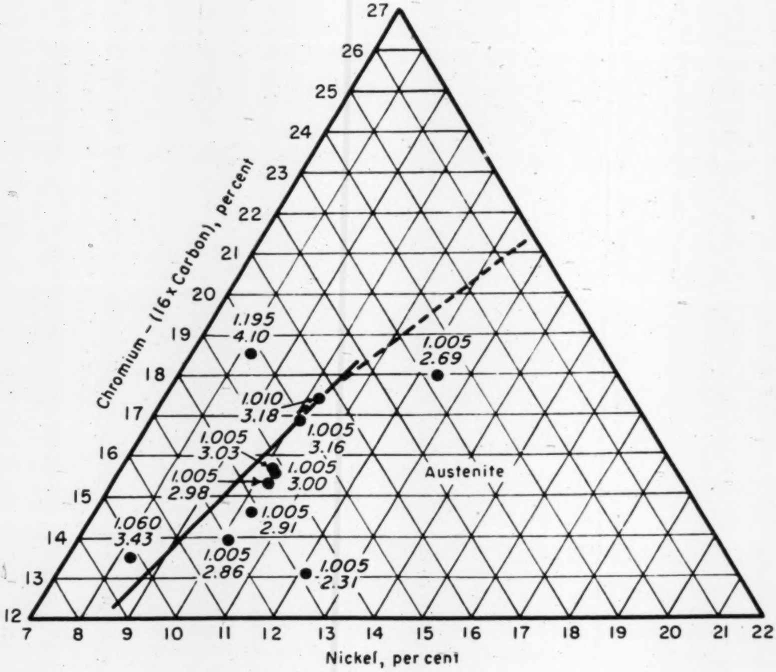


FIG. 8.—Effect of Composition on the Structural Stability of the Test Materials After Aging 48 hr at 1400 F.

The positions on the iron-chromium-nickel diagram occupied by the various HF compositions studied are shown in Fig. 8. Also indicated are their magnetic permeabilities as determined after aging at 1400 F for 48 hr. In this figure, the factor [(% Cr − (16 × % C)] was used rather than chromium content itself in order to compensate for the variation in carbon content of the test materials. The boundary defined by the Gow-Harder equation is indicated by the dotted line. It can be seen from the data given in Fig. 8 that the austenite-phase-field boundary for HF compositions probably must pass between the point representing heat AAO and that representing heat AAO-1 and somewhere to the right of the point for heat AAL. Unfortunately, no material having a composition that would place it just to the right of AAL on the diagram was available for examination. Likewise, only one composition in the upper right-hand portion of the HF area involved was available. Thus, the location of the boundary could not be established with any precision. Considerably more microstructural and magnetic permeability data will be required to establish the phase-field boundary with confidence.

On the basis of the data at hand, it was assumed that the boundary could be approximated by a straight line passing between compositions AAO and AAO-1, with AAN, AAS, and AAL on the upper left. The upper right-hand region has been thoroughly investigated by Gow and Harder, and, on the basis of their results, it is believed that the slope of the boundary changes somewhat, as indicated by the positions of the solid and dotted lines in Fig. 8.

An equation for a straight line defining the boundary as described above is as follows:

$$\frac{\%\,\mathrm{Cr} - (16 \times \%\,\mathrm{C}) + 15}{\%\,\mathrm{Ni}} = 3.17$$

This equation is used in the same manner as the Gow-Harder equation, that is, when the ratio is less than 3.17, the alloy should be entirely austenitic, when greater than 3.17, partially ferritic. Ratio factors have been calculated for each of the heats using this equation and are noted in Fig. 8. This equation has also been applied to a number of HF compositions reported by Avery, Wilks, and Fellows (1) and was found to predict microstructures that were consistent with the observations of these investigators. However, the phase boundary given by the equation suggested here can be regarded only as tentative until supported or modified by more data.

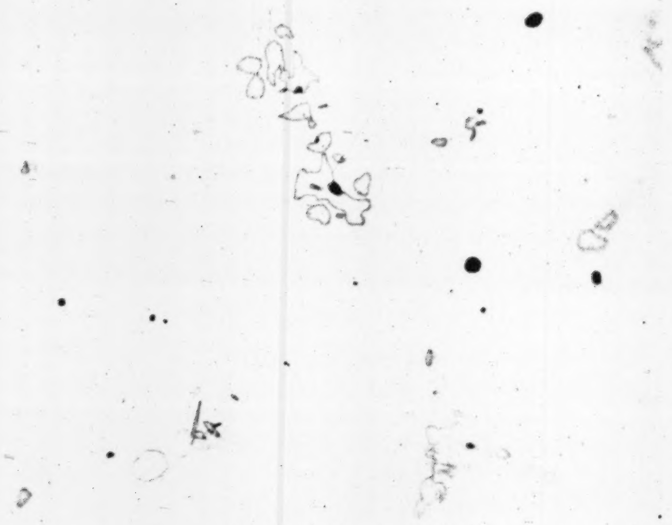
Because the information upon which the boundary was based was obtained on samples reheated at 1400 F, it may be regarded as relating roughly to the 1400-F isothermal section of the constitution diagram. Moreover, the suggested boundary cannot be regarded as a true equilibrium phase boundary, but instead indicates a condition of metastable equilibrium. This circumstance arises from the fact that evidence has been found to indicate that, on continued aging at intermediate temperatures, the ferrite in ferrite-containing compositions may disappear. This is discussed below in connection with sigma formation in the alloy. Thus, the suggested boundary and equation are intended only to distinguish those compositions in which ferrite may be found from those in which ferrite is not found—in other words, the limit of austenite stability.

Sigma-Phase Formation:

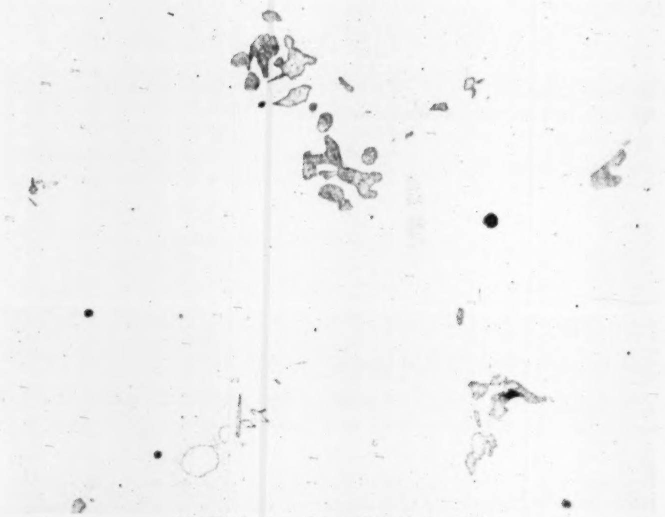
For the determination of the presence of sigma phase in the experimental materials, metallographic examination was used. The etchants and staining reagents used in identifying the phase were as follows:

Mixed acids..........	(4 parts HCl:1 part HNO_3)
Kalling's reagent......	($CuCl_2$ plus HCl in alcohol)

No evidence of sigma phase was found in any of the test materials in the as-cast condition. Moreover, no sigma was found in test specimens that had been aged 24 or 48 hr at 1400 or 1600 F. However, because sigma formation is likely to be a slow process, it was considered that the data obtained from samples aged the relatively short times of 24 and 48 hr were an insufficient basis for deciding whether or not sigma actually could form in the HF alloy. Therefore, samples of nine of the experimental heats were given long-time aging treatments in air at 1400 and 1500 F. (Material from heat AAL was not available for these tests.)



(*a*) Etched with mixed acids.



(*b*) Etched with Kalling's reagent.

FIG. 9.—Microstructure of Material AAN After Aging at 1400 F for 3000 hr.

Stained phase is believed to be sigma and the clearly outlined phase ferrite. Carbides are very faintly visible. Matrix is austenite.

These temperatures were chosen as being within the normal sigma-formation range. After approximately 1700 hr, sufficient material was cut from the samples for metallographic examination. Aging was then continued until a total of 3000 hr had been obtained, and at the end of this period, the samples were again examined under the microscope. In addition, their magnetic permeabilities were determined.

Metallographic examination disclosed the presence of sigma in heat AAN after aging both 1700 and 3000 hr at each temperature. The sigma phase was also believed to have been observed in heat AAS-1 after the same treatments. More sigma was observed in the specimens heated at 1400 F than in those heated at 1500 F. This is probably to be expected in view of the general observation that sigma does not form at all at temperatures above about 1600 F. The sigma found in heat AAN is shown in Fig. 9.

Sigma was not found in the other materials tested. It will be recalled that heat AAN was high in chromium and low in nickel, while heat AAS-1 was exceptionally low in carbon content. The finding of sigma in these two heats establishes the possibility that sigma can sometimes form in the standard HF alloy but suggests that extreme deviation of the alloy from the mean composition is required for the development of such susceptibility.

TABLE III.—MAGNETIC PERMEABILITIES OF HEATS AAN AND AAS-1.

Heat	As-Cast	Aged at 1400 F		Aged at 1500 F 3000 hr
		48 hr	3000 hr	
AAN	1.060	1.195	1.025	1.095
AAS-1	1.015	1.040	1.005	1.005

Of great interest was the fact that the two heats in which sigma was believed to have been found after long-time aging both contained ferrite in the as-cast condition and after aging 48 hr at 1400 F. Of equal interest was the relation between aging time and magnetic permeability for these heats, as shown in Table III. Although aging 48 hr at 1400 F produced an increase in the amount of ferrite in both materials, continued aging to 3000 hr decreased the amount of ferrite, as indicated by the decrease in permeability; at the same time, the sigma phase appeared. It can be inferred that a similar phenomenon took place at 1500 F, except that less sigma formed and more ferrite was retained in the case of heat AAN. These observations permit the postulation that the sigma phase replaced the ferrite and that, in these alloys, ferrite is an intermediate phase in the process of forming sigma from austenite. It may also be speculated, by the same token, that any HF alloy heat which contains ferrite is susceptible to sigma-phase formation.

It cannot be stated definitely, on the basis of the data available, that the converse is true, that is, that fully austenitic HF alloy heats are immune to sigma formation. However, the fact that sigma was not found in any of the fully austenitic materials tested supports the suggestion that such is the case.

Heat AAN, containing 23.6 per cent chromium and 8.2 per cent nickel, together with mean amounts of the other elements under study, showed itself to be readily susceptible to ferrite formation and to sigma formation. Because of the tendencies exhibited by this heat and in the light of other information relating composition to microstructure, the Alloy Casting Inst. reviewed its chemical specification for the HF alloy. As an outcome, the minimum nickel content was raised from 8 to 9 per cent. It was considered that, because of the austenitizing power of nickel, this increase in nickel content would materially reduce the probability of ferrite or sigma formation in the HF alloy.

ROOM-TEMPERATURE TENSILE PROPERTIES

It is recognized that room-temperature tensile properties bear little relationship to high-temperature performance. However, they sometimes give an indication of whether or not a particular heat is of normal quality and, in addition, are occasionally requested by engineers.

Room-temperature tensile properties were therefore obtained for the HF alloy.

The materials were tested both in the as-cast condition and after aging 24 and 48 hr at 1400 F. The purpose of the aging treatments was to place the material in a comparatively stable microstructural condition. The treatment serves both to relieve casting strains and to precipitate secondary carbides. The results are given in Table IV.

TABLE IV—ROOM-TEMPERATURE TENSILE PROPERTIES OF TEST MATERIALS.

Heat	Prior Heat Treatment	Tensile Strength, psi	Proportional Limit, psi	Yield Strength, psi		Elongation, per cent	Reduction of Area, per cent
				0.1 per cent Deformation	0.2 per cent Deformation		
AAK	As-cast	89 200	26 200	42 700	45 700	36	29
	1400 F—24 hr	99 600	19 500	42 700	46 900	18	17
	1400 F—48 hr	90 000	22 500	42 400	46 900	13	15
AAL	As-cast	84 200	24 200	43 200	45 900	38	31
	1400 F—24 hr	103 800	24 000	46 100	50 400	14	16
	1400 F—48 hr	103 000	24 900	44 400	50 400	13	12
AAM	As-cast	89 200	22 500	42 700	47 900	21	21
	1400 F—24 hr	98 300	19 500	41 900	46 800	20	14
	1400 F—48 hr	96 800	23 700	43 200	47 900	14	15
AAN	As-cast	99 300	27 500	46 700	51 700	43	36
	1400 F—24 hr	109 700	22 500	46 400	51 700	16	14
	1400 F—48 hr	109 600	27 500	48 900	54 200	14	14
AAO	As-cast	85 600	27 900	41 900	43 900	47	40
	1400 F—24 hr	92 100	18 000	39 400	43 100	22	24
	1400 F—48 hr	91 800	22 500	39 200	39 900	21	28
AAO-1	As-cast	75 500	29 500	37 500	38 500	34	30
	1400 F—24 hr	93 000	20 500	37 500	41 000	29	26
AAP	As-cast	94 600	23 700	44 200	50 400	21	24
	1400 F—24 hr	100 200	18 000	43 900	49 100	12	12
	1400 F—48 hr	93 800	24 900	44 200	49 400	9	9
AAQ	As-cast	83 800	21 200	40 400	44 200	32	33
	1400 F—24 hr	95 800	19 500	40 800	45 700	18	15
	1400 F—48 hr	99 800	25 100	41 800	45 800	17	17
AAR	As-cast	88 600	23 700	45 400	47 700	39	33
	1400 F—24 hr	108 800	28 000	49 400	53 900	16	19
	1400 F—48 hr	105 000	27 500	48 200	53 200	13	11
AAS-1	As-cast	77 100	16 300	34 200	36 900	54	60
	1400 F—24 hr	78 500	18 500	31 500	33 000	56	52
AAW	As-cast	81 000	18 500	37 000	40 000	29	22
	1400 F—24 hr	94 000	20 500	39 000	44 000	13	13

Austenitic Compositions Containing Mean Amounts of Carbon and Nitrogen:

The results obtained from three heats (AAK, AAQ, and AAM) were used to establish the room-temperature tensile properties of fully austenitic alloys at a carbon level of about 0.33 per cent and a nitrogen content of about 0.10 per cent. These three materials had normal silicon and manganese contents. For the as-cast condition, the average tensile strength was 87,400 psi and the average yield strength (0.2 per cent deformation) was 45,900 psi. The average elongation for this condition was 29.8 per cent. The average tensile strength, yield strength, and elongation of these materials, after aging at 1400 F, were 96,700 psi, 46,700 psi, and 16.8 per cent, respectively. The values for the aged specimens were treated together for two reasons:

1. Only relatively small differences existed between the average properties

obtained for specimens aged 24 hr and those obtained for specimens aged 48 hr.

2. Each aging period was represented by only a single test.

It is seen that the aging treatments increased tensile strength at the expense of ductility but had little effect on yield strength. However, examination of Table IV shows that aging had a fairly consistent effect on proportional limit: the 24-hr treatment tended to reduce it, whereas the 48-hr treatment tended to improve it slightly.

Effect of Carbon Content in Austenitic Compositions:

The influence of carbon on the room-temperature tensile properties of fully austenitic compositions was indicated by the results obtained for heats AAO-1, AAQ, and AAP. For as-cast material, the tensile strength increased from 75,500 to 94,600 psi, the yield strength increased from 38,500 to 50,400 psi, while the elongation decreased from 34 to 21 per cent, as the carbon content increased from 0.22 to 0.43 per cent. Thus, carbon had a pronounced strengthening effect.

The corresponding ranges of properties for material aged at 1400 F for 24 hr were as follows: 93,000 psi tensile strength, 41,000 psi yield strength, and 29 per cent elongation, for the low-carbon material; 100,200 psi tensile strength, 49,100 psi yield strength, and 12 per cent elongation for the high-carbon material. Again, the aging treatment affected tensile strength and ductility to a greater degree than yield strength. In addition, there was a tendency for the strengthening effect to be more pronounced the lower the carbon content of the material. For example, the tensile strength of heat AAO-1 (0.22 per cent carbon) was increased 17,500 psi by aging 24 hr at 1400 F, whereas that of heat AAP (0.43 per cent carbon) was increased only 5600 psi by the same treatment. The ductility of heat AAP was quite adversely affected by the aging treatment, and it can be postulated that the material had begun to "overage." This view is supported by the results obtained after the material had been aged 48 hr at 1400 F. The latter treatment caused the tensile strength to fall below that of the original as-cast specimens.

Effect of Nitrogen Content in Austenitic Compositions:

The effect of increasing the nitrogen content from 0.039 per cent (heat AAW) to 0.175 per cent (heat AAR) was to increase the tensile strength from 81,000 to 88,600 psi, the yield strength (0.2 per cent elongation) from 40,000 to 47,700 psi, and the elongation from 29.0 to 38.6 per cent, for material in the as-cast condition. These results show that nitrogen enhances the strength of the HF alloy in the as-cast condition. However, when the results are compared with those of the three heats (AAK, AAQ, and AAM) used as the basis of comparison for the austenitic compositions, it is seen that the strengthening effect is not great.

The tensile properties obtained from aged specimens of heat AAW were 94,000 psi tensile strength, 44,000 psi yield strength, and 13 per cent elongation. The corresponding properties of heat AAR were 108,800 psi tensile strength, 53,900 psi yield strength, and 16 per cent elongation. These values suggest that nitrogen may contribute more to aging response than does carbon and, perhaps, at less sacrifice in ductility.

Partially Ferritic Compositions:

It was of interest to note that the partially ferritic heat AAN, with a carbon content about the same as that possessed by the fully austenitic materials used as the basis of comparison, had superior room-temperature tensile properties. Not only were the properties superior for material as-cast, but the heat also attained the highest tensile strength and yield strength of the group upon aging. Moreover, the ductility after aging was comparatively good.

Heat AAS-1, also partially ferritic, was a low-strength, ductile material. However, this circumstance can undoubtedly be attributed to its low carbon content.

ELEVATED-TEMPERATURE TENSILE PROPERTIES

In Table V are listed the tensile properties of the test materials at 1400 F. This temperature was chosen because it approximates the midpoint of the HF alloy's normal service temperature range (1200 to 1600 F). All specimens were aged 48 hr at 1400 F prior to testing.

TABLE V.—TENSILE PROPERTIES OF THE TEST MATERIALS AT 1400 F.

Heat	Tensile Strength, psi	Proportional Limit, psi	Yield Strength, psi		Elongation, per cent	Reduction of Area, per cent
			0.1 per cent Deformation	0.2 per cent Deformation		
AAK	35 000	12 750	21 000	23 000	21	33
AAL	34 700	9 750	20 000	22 000	13	27
AAM	37 000	8 250	19 250	21 500	22	23
AAN	39 300	13 450	21 500	23 700	21	24
AAO	36 350	9 750	18 550	20 500	19	22
AAP	37 950	10 500	21 300	23 300	18	29
AAQ	35 550	11 000	19 300	21 050	17	29
AAR	40 550	11 000	22 700	25 200	17	32

All heats contained approximately 1.0 per cent silicon and 0.8 per cent manganese.

As in the case of the room-temperature tension tests, the specimens were machined to standard 2-in. gage length and 0.505-in. diameter. The same crosshead speed was used (0.02 in. per min). A special high-temperature extensometer was mounted directly to the gage length. Chromel-Alumel thermocouples were attached at the center and just outside each end of the gage length. The test specimen, together with thermocouples and the extensometer, was placed in a wire-wound furnace which was mounted between the plates and head of the test machine. The temperature was kept within ASTM specifications for a test of this type. As in the case of the room-temperature tests, the stress-strain curve was plotted by an automatic stress-strain recorder until the yield value for 0.2 per cent deformation was obtained.

Variations in chromium and nickel contents of fully austenitic material, as exemplified by heats AAK, AAM, and AAQ, did not exert a strong influence on the tensile strength, yield strength, or elongation under the test conditions. The slightly lower value for elongation obtained for heat AAQ is believed to have resulted from some irregularity in the test, because the data obtained from stress-rupture and thermal-fatigue tests at this temperature indicated that this material possessed ductility equal or superior to that of either heat AAK or heat AAM.

The effect of carbon content on the strength and elongation of austenitic compositions at this temperature (1400 F) was not too pronounced.

With regard to the effect of nitrogen on austenitic compositions, it was observed that when the nitrogen content was increased from 0.096 to 0.175 per cent, the tensile and the yield strengths were increased from 35,550 to 40,550 psi and 21,050 to 25,200 psi, respectively, with no significant change in elongation. Nitrogen seemed to be a more potent strengthener than was carbon under the conditions of test.

Of interest also was the comparatively high strength and good ductility of the partially ferritic heat AAN.

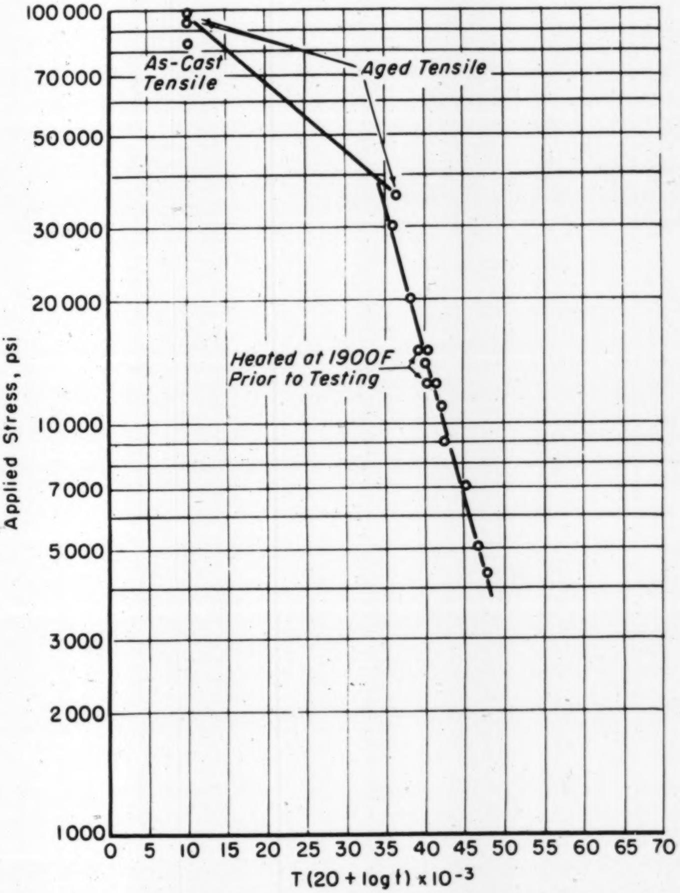


FIG. 10.—Larson-Miller Plot of Rupture Times Obtained for Heat AAQ.

STRESS-RUPTURE AND CREEP PROPERTIES

The determination of the stress-rupture and creep properties of the experimental HF alloys was carried out on specimens that were in the as-cast and machined condition. Some additional data were also obtained on specimens that had been held at 1900 F for periods up to 12 hr prior to testing. The test temperatures used were 1200, 1400, and 1600 F.

In summarizing the data, two methods were employed. One was the standard method involving interpolation and, in some cases, extrapolation of the conventional semilogarithmic plot of stress *versus* time or minimum creep rate. The other method was that of Larson and Miller (3). Briefly, this relates test temperature to rupture time through the use of the equation:

$$T\,(C + \log t) = \text{constant}$$

where T is the absolute temperature (459 + test temperature, deg Fahr), C is a constant which Larson and Miller found to be 20, and t is the rupture time.

TABLE VI.—STRESSES FOR RUPTURE IN 100, 200, AND 800 HR AND FOR MINIMUM CREEP RATES OF 0.0005 AND 0.0001 PER CENT PER HR.

Alloy	Rupture Stress, psi						Stress for Minimum Creep Rate, psi, Semilog Plot	
	100 hr		200 hr		800 hr		0.0005 per cent per hr	0.0001 per cent per hr
	Semilog Plot	Larson-Miller Plot	Semilog Plot	Larson-Miller Plot	Semilog Plot	Larson-Miller Plot		
Tested at 1600 F								
AAK	6 500	6 600	6 000	6 000	5 000	4 700	5 500	4 500
AAL	6 500	7 300	6 000	6 800	...	5 800	...	...
AAM	7 000	6 600	6 500	5 900	...	4 700	...	...
AAN	8 500	7 900	7 500	7 200	6 000	5 900	6 000	4 500
AAO-1	6 000	5 800	5 500	5 300	4 500	4 200	4 500	3 500
AAP	8 000	7 900	7 500	7 200	6 000	5 900	6 500	...
AAQ	6 500	6 300	6 000	5 700	5 000	4 700	5 000	4 500
AAR	6 000	6 100	5 500	5 400	4 000	4 200	5 000	4 500
AAW	8 000	7 800	7 000	7 200	5 500	6 000	...	...
Tested at 1400 F								
AAK	15 500	15 500	14 000	14 000	...	11 000	...	...
AAL	14 000	13 000	13 500	12 000	12 000	10 500	...	...
AAM	14 500	14 500	13 500	13 500	...	10 500	...	...
AAN	15 500	16 500	...	15 000	...	12 500	...	...
AAO-1	11 500	12 500	...	11 500	...	9 300	...	...
AAP	16 000	16 000	14 500	14 500	...	13 000	..	...
AAQ	13 000	13 100	12 000	12 000	9 500	10 000	9 000	...
AAR	14 000	15 000	13 500	13 000	12 000	10 500	...	...
AAW	15 000	15 500	14 000	14 000	13 000	12 000	14 000	...
Tested at 1200 F								
AAK	34 000	36 000	32 500	32 000	...	27 000	...	...
AAL	29 000	23 000	28 000	21 000	...	18 500	...	...
AAM	31 000	33 500	30 000	30 000	...	25 000	...	...
AAN	34 000	34 000	31 500	31 000	27 000	27 000	25 000	21 000
AAO-1	27 000	27 000	25 000	25 000	21 000	21 000	...	...
AAP	32 000	32 000	30 500	30 000	...	25 000	...	...
AAQ	28 500	27 500	27 000	25 000	22 000	21 000	23 500	...
AAR	36 000	36 000	32 500	33 000	25 500	27 000	26 000	...
AAW	30 500	30 000	29 500	28 000	...	24 000	...	...

By using the above equation to obtain values for elevated-temperature tension and stress-rupture test data and plotting the values against the logarithm of the applied stress, points through which a straight line could be drawn were obtained. The Larson-Miller-type plot obtained for heat AAQ is presented in Fig. 10. The interesting feature of this type of plot is that all of the data obtained, rather than just the data obtained at a given temperature, are involved in the interpolation of the rupture stresses.

The results from both methods of plotting are summarized in Table VI. Scatter bands showing the stress-rupture properties at 1200, 1400, and 1600 F of all the experimental heats meeting the HF chemical specification are shown in the form of conventional semilogarithmic plots in Fig. 11. It will be noted that the correlation between the results obtained by means of the two methods is quite good except, perhaps, for data obtained at 1200 F.

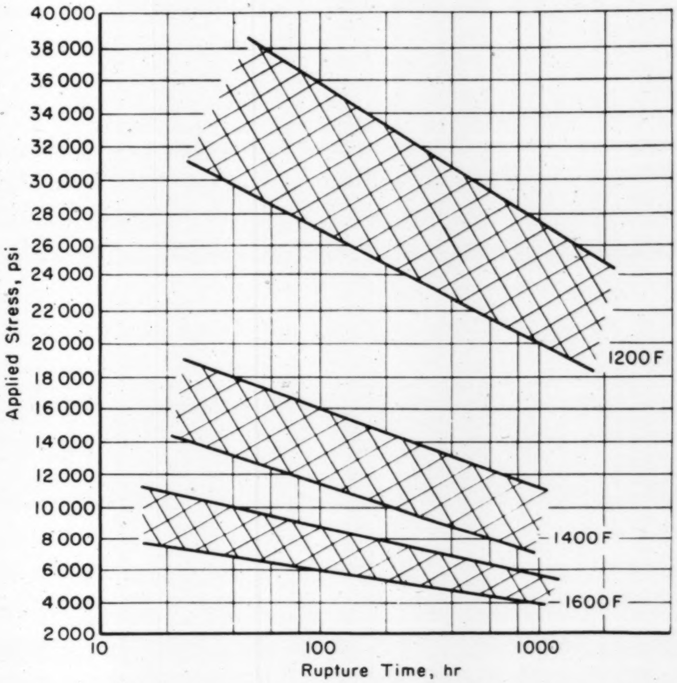


FIG. 11.—Semilogarithmic Plot of Rupture Properties of HF Heats Tested in the As-Cast Condition.

Austenitic Compositions Containing Mean Amounts of Carbon and Nitrogen:

The group of fully austenitic materials in this category comprised heats AAK, AAQ, and AAM.

At 1600 F, there was very little difference in properties among these materials. The 100-hr rupture stress was of the order of 6500 psi, and the limiting creep stress for a minimum creep rate of 0.0001 per cent per hr was about 4500 psi. However, at the lower test temperatures, differences among the heats appeared to develop. At 1400 F, heat AAK possessed a 100-hr rupture stress of 15,500 psi, whereas the 100-hr rupture stresses for heats AAM and AAQ were 14,500 and 13,500 psi, respectively. At 1200 F, heat AAK possessed a 100-hr rupture stress of 34,000 psi, with the 100-hr rupture stresses for heats AAM and AAQ being 31,000 and 28,500, respectively. No estimate of the limiting creep stresses for a minimum creep rate of 0.0001 per cent per hr at the latter two temperatures could be obtained from the data available.

These data suggested that as test temperature increased, differences among the materials tended to be minimized. At the lower temperature, there were indications that the material with lower chromium and higher nickel contents (heat AAK) was somewhat stronger than the other austenitic compositions under test.

Effect of Carbon Content in Austenitic Compositions:

Three compositions were studied to determine the effect of carbon on stress-rupture properties: heat AAO-1 (0.22 per cent carbon), heat AAQ (0.31 per cent carbon), and heat AAP (0.43 per cent carbon). They contained average amounts of the other elements.

The effect of decreasing the carbon content from 0.31 per cent to 0.22 per cent was to decrease moderately the load-carrying ability. For example, at 1600 F the 100-hr rupture stress was reduced from 6500 psi to 6000 psi, and at 1400 F this stress was reduced from 13,000 psi to 11,500 psi. At 1200 F, the 100-hr rupture stress was reduced from 28,500 psi to 27,000 psi.

The effect of increasing the carbon content from 0.31 per cent to 0.43 per cent was to increase substantially the load-carrying ability at the three test temperatures. At 1600 F, the 12-point increase in carbon content increased the 100-hr rupture stress from 6500 to 8000 psi. It increased the 100-hr rupture stress from 13,000 psi to 16,000 psi at 1400 F, and from 28,500 psi to 32,000 psi at 1200 F.

Effect of Nitrogen Content in Austenitic Compositions:

Two test materials, in addition to heat AAQ, were used for the purpose of determining the effect of nitrogen content. These materials were heat AAW, containing only 0.039 per cent nitrogen, and heat AAR, containing 0.175 per cent nitrogen. Both contained mean amounts of the other elements.

No effect due to nitrogen could be clearly discerned from the data. At 1400 and 1600 F, the material with the lowest nitrogen content appeared to be somewhat stronger than the others. At 1200 F, the high-nitrogen material appeared to be strongest.

Partially Ferritic Compositions:

The two partially ferritic compositions were heat AAL (18.8 per cent chromium, 8.31 per cent nickel) and heat AAN (23.6 per cent chromium, 8.2 per cent nickel). Both contained about 0.33 per cent carbon.

The approximate 100-hr rupture stresses of these compositions were as follows:

Heat	Rupture Stress in 100 hr, psi		
	1200 F	1400 F	1600 F
AAL (R.F. 3.43)[a]	29 000	14 200	6 500
AAN (R.F. 4.10)[a]	34 000	15 200	8 500

[a] R.F. = ratio factor.

In general, heat AAL was about as strong as the weakest wholly austenitic material possessing a similar carbon content (AAQ), and heat AAN was about as strong as the strongest wholly austenitic material having a similar carbon content (AAK).

Heat AAL performed about as would be expected for a partially ferritic material. The reason for the high strength of heat AAN is not known. However, it is believed that the presence of the *sigma phase may have been an important factor.* Metallographic examination disclosed that, after aging at 1400 F for 3000 hr, this material developed a relatively large amount of sigma. Sigma also formed in this material after aging at 1500 F for the same period. No sigma was found in heat AAL or in any of the other alloys after these aging treatments.

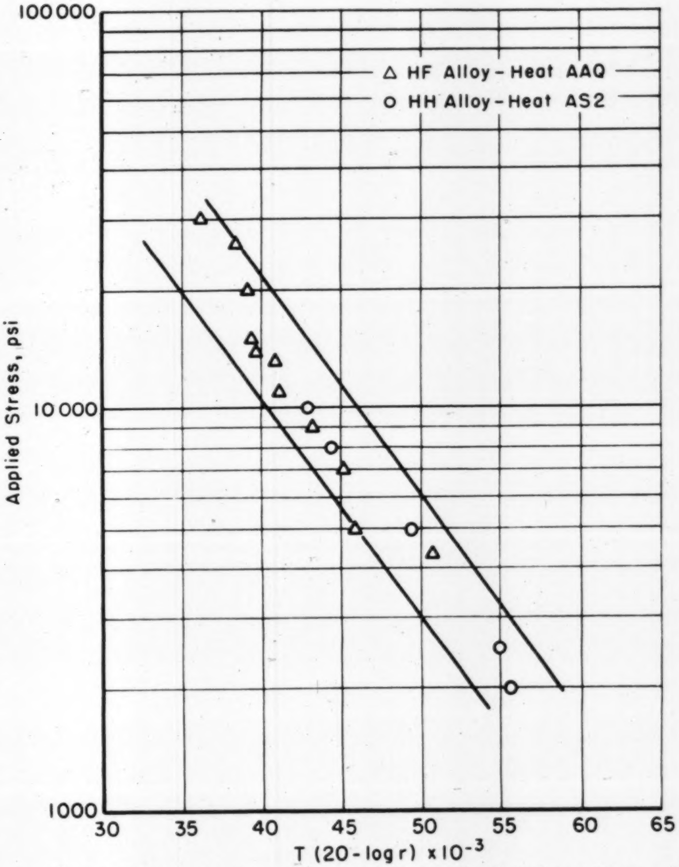


FIG. 12.—Larson-Miller Plot of Minimum Creep Rates for Individual Heats of HF and HH Alloys.

NOTE.— r = minimum creep rate.

Comparison of HF and HH Grades:

Field experience indicates that, in numerous applications, the high-temperature strength properties of the HF alloy are comparable with those of the HH grade. The latter is a 26 per cent chromium - 12 per cent nickel type, available with either an entirely austenitic structure or a partially ferritic structure. In the entirely austenitic form, it possesses superior high-temperature strength to that obtainable when part of the matrix is ferrite.

Some creep-rate data, available from an experimental heat of austenitic HH alloy, are shown in the form of a Larson-Miller plot in Fig. 12. Data for the HF heat, AAQ, of comparable carbon and nitrogen content are given for comparison. It is seen that the performance of the two materials was closely similar. The compositions of the materials are as follows:

Type	Heat	Composition, per cent					
		Carbon	Chromium	Nickel	Silicon	Manganese	Nitrogen
HF....	AAQ	0.31	20.6	10.2	0.92	0.77	0.096
HH...	AS2	0.33	24.6	12.5	0.97	0.84	0.087

TABLE VII.—THERMAL-FATIGUE PROPERTIES OF THE TEST MATERIALS.

Heat	Condition	Test Temperature, deg Fahr	Cycles to Crack[a]	Deformation, in.[b]
Austenitic Heats Containing Mean Amounts of Carbon and Nitrogen				
AAQ	As-cast	1200	167	1/64 (150)
AAK	As-cast	1400	155	10/64 (150)
AAQ	As-cast	1400	302	10/64 (150)
AAM	As-cast	1400	218	15/64 (150)
AAK	Held 6 hr at 1900 F	1400	407	33/64 (400)
AAQ	Held 6 hr at 1900 F	1400	905	34/64 (400)
AAM	Held 6 hr at 1900 F	1400	702	29/64 (400)
AAK	Held 12 hr at 1900 F	1400	649	38/64 (600)
AAQ	Held 12 hr at 1900 F	1400	647	42/64 (600)
AAM	Held 12 hr at 1900 F	1400	948	30/64 (600)
AAK	As-cast	1600	220	42/64 (200)
AAQ	As-cast	1600	402	41/64 (200)
AAM	As-cast	1600	285	40/64 (200)
AAQ	Held 6 hr at 1900 F	1600	484	51/64 (450)
Partially Ferritic Heats Containing Mean Amounts of Carbon				
AAN	As-cast	1200	171	2/64 (150)
AAN	As-cast	1400	210	1/64 (20)
AAL	As-cast	1400	40	3/64 (20)
AAN	Held 6 hr at 1900 F	1400	518	34/64 (500)
AAN	Held 12 hr at 1900 F	1400	915	16/64 (75)
AAL	Held 12 hr at 1900 F	1400	80	23/64 (75)
AAN	As-cast	1600	280	41/64 (250)
AAN	Held 6 hr at 1900 F	1600	322	52/64 (300)
Other Partially Ferritic Compositions				
AAO	As-cast	1400	216	14/64 (200)
AAO	Held 12 hr at 1900 F	1400	727	40/64 (700)

[a] Value listed is, in most cases, the average of two or more tests.

[b] Value listed is the average of two or more tests. For purposes of comparison, the deformation was measured at the number of cycles indicated within parentheses.

THERMAL-FATIGUE PROPERTIES

The thermal-fatigue test used in this work was developed at Battelle Memorial Inst. during previous research carried out for the Alloy Casting Inst. The test is designed to determine the ability of an alloy to resist hot cracking and distortion when subjected to moderately rapid thermal cycling. The development of the test technique and apparatus have been described by Jackson (**4**) and by Avery and Wilks (**5**). Briefly, it involves heating a disk-shaped specimen over a gas flame and then quenching it by means of a jet of water after the specimen has been at the test temperature for a selected period of time. The flame impinges on the center of the specimen, and heating and expansion are greatest at that point; therefore, tensile stresses are set up in the periphery of the specimen. Stress raisers in the form of regularly spaced holes are included, as shown in Fig. 1.

The test cycle consists of heating the specimen to temperature in about 5 min, holding it at the test temperature for 5 min, followed by quenching it to room temperature in approximately 60 sec.

The distribution of forces in the specimen during the heating and cooling is such that the specimen buckles or dishes downward as the test progresses. The amount the center point of the specimen has moved downward is referred to as the deformation. When cracks develop, they occur either between holes or between an outer hole and the periphery of the specimen. When a complete test is considered to have been reached, cracks will have developed in both places. This is called "cycles to crack."

Thermal-fatigue tests were performed at 1200, 1400, and 1600 F. Most of the materials were tested in the as-cast and machined condition, as well as after heating at 1900 F for 6 and 12 hr. All tests were made in duplicate, with the results shown in Table VII.

There were varying degrees of divergence between the results obtained from duplicate specimens. In fact, in some cases the discrepancies were quite wide. The reason for this is not known, though it is speculated that it was related to inhomogeneities in the specimens. It is questionable, therefore, that the thermal-fatigue results can be interpreted narrowly. However, interesting trends reasonably well supported by the data are evident.

Examination of the data obtained for austenitic heats, containing mean amounts of carbon and nitrogen, suggests that susceptibility to cracking tended to decrease as the test temperature was increased. Susceptibility to cracking tended to be greater in the material with the higher nickel content. Holding the materials at 1900 F for 6 hr prior to testing markedly reduced cracking tendency. Little seemed to be gained,

TABLE VIII.—THERMAL-FATIGUE PROPERTIES AT 1600 F FOR SEVERAL CASTING ALLOYS IN THE AS-CAST CONDITION.

ACI Alloy Type	Heat	Chemical Composition, per cent						Cycles to Cause Failure	Deformation at Failure, in.
		Carbon	Chromium	Nickel	Silicon	Manganese	Nitrogen		
0.41 TO 0.45 PER CENT CARBON LEVEL									
HF............	AAP	0.43	20.76	10.09	0.93	0.79	0.10	257	0.64
HH............	TU	0.45	25.5[a]	11.5[a]	1.35[a]	0.80[a]	0.09[a]	54	0.11
HK............	PG	0.41	25.0[a]	20.5[a]	1.50[a]	0.85[a]	0.07[a]	27	0.19
HT............	TQ	0.45	16.0[a]	36.0[a]	1.35[a]	0.80[a]	...	13	0.05
0.28 TO 0.31 PER CENT CARBON LEVEL									
HF............	AAQ	0.31	20.6	10.2	0.92	0.77	0.096	402	0.72
HH............	TK	0.30	24.8	12.4	1.38	0.96	0.09	54	0.25
HK............	PB	0.31	27.9	19.0	1.50[a]	0.85[a]	0.07[a]	26	0.28
HT............	TP	0.28	16.0[a]	36.0[a]	1.35[a]	0.80[a]	...	56	0.20

[a] Intended amounts.

however, by extending the holding time from 6 to 12 hr.

In general, it appeared that increasing the carbon content of austenitic material tended to increase susceptibility to cracking and reduce deformation.

The influence of nitrogen could not be clearly discerned. It appeared, however, that when the nitrogen content was high susceptibility to cracking was increased and deformation was decreased. Holding the high-nitrogen material at 1900 F prior to testing was ineffectual. However, cracking tendency was markedly decreased and deformation increased by this treatment in the case of the low-nitrogen material.

The results obtained for the partially ferritic heats were extremely erratic. Heats AAN and AAO performed as well as did the entirely austenitic materials when tested both in the as-cast condition and when heated at 1900 F. The other unbalanced heat gave comparatively poor results. Possibly in the case of the latter heat some sigma phase formed during the tests and influenced the results.

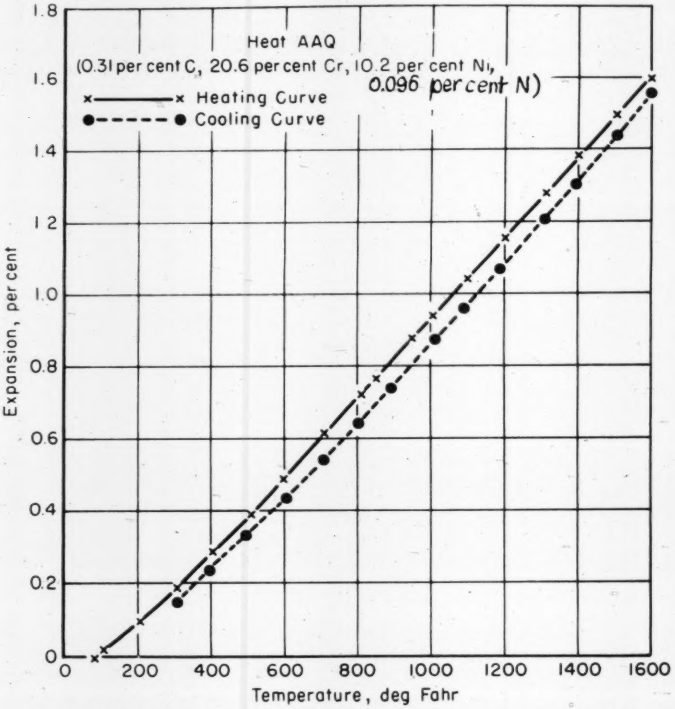


FIG. 13.—Heating and Cooling Curves Obtained for Heat AAQ.

In general, the results suggested that steps which tended to increase the high-temperature strength of the alloy tended also to increase susceptibility toward cracking. Conversely, steps which reduced high-temperature strength tended to increase resistance to cracking. The pretreatment at 1900 F may be placed in the latter category because it tends to agglomerate or spheroidize the excess primary carbides.

In Table VIII, a comparison is made of

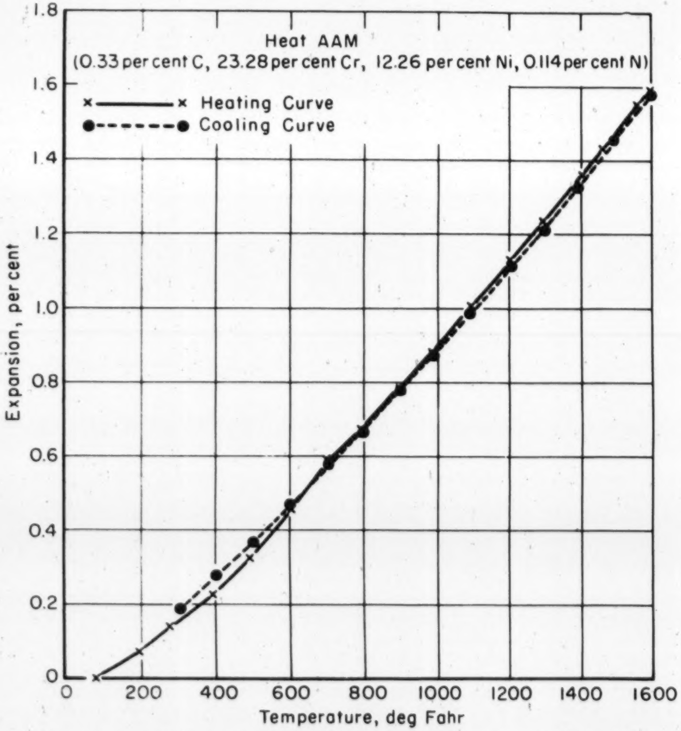


FIG. 14.—Heating and Cooling Curves Obtained for Heat AAM.

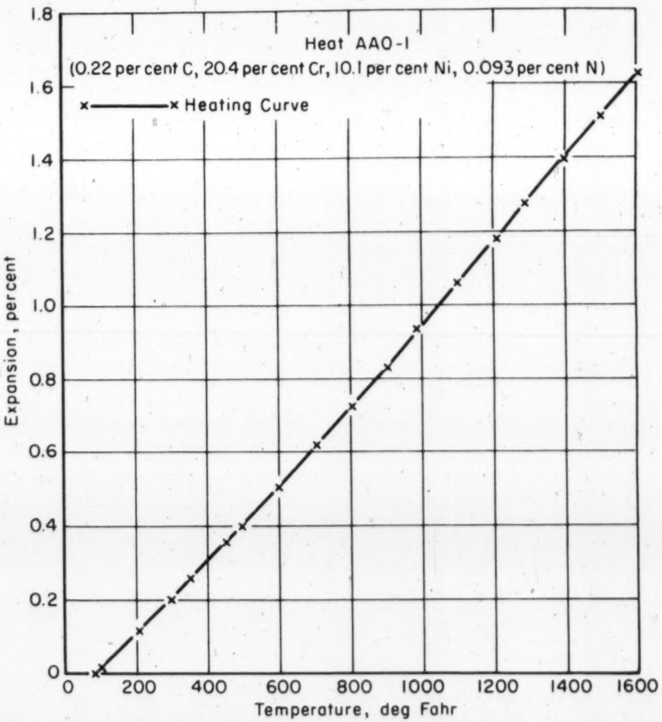


FIG. 15.—Heating Curve Obtained for Heat AAO-1.

the thermal-fatigue properties of several grades of heat-resisting casting alloys. The alloy types used in the comparison include the HH grade (26 per cent chromium - 12 per cent nickel), the HK grade (26 per cent chromium - 20 per cent nickel), and the HT alloy (15 per cent chromium - 35 per cent nickel). All materials were tested in the as-cast condition; no preliminary heat treatment was used. Two levels of carbon content are represented for all materials—about 0.43 per cent and 0.30 per cent carbon. It is evident that the resistance of the HF alloy to failure was markedly greater than that of the other materials.

TABLE IX.—THERMAL EXPANSION AND CONTRACTION DATA FOR MATERIAL AAQ.

Temperature Interval, deg Fahr	Average Linear Coefficients	
	Expansion, in. per in. per deg Fahr	Contraction, in. per in. per deg Fahr
80 to 200	7.4×10^{-6}	...
80 to 400	8.7	7.4×10^{-6}
80 to 600	9.4	8.3
80 to 800	9.9	8.9
80 to 1000	10.1	9.4
80 to 1200	10.3	9.6
80 to 1400	10.5	9.9
80 to 1600	10.5	10.2

Note.—Cycle of test:
1. Heating—room temperature to 1600 F
Total expansion....... 1.596 per cent
2. Holding—16½ hr at 1600 F
Contraction produced at 1600 F............ 0.041 per cent
3. Cooling—1600 F to room temperature
Total change in length caused by test (contraction)........... 0.063 per cent

Thermal-Expansion Properties

The thermal-expansion properties of three austenitic compositions were determined over the range from room temperature to 1600 F. The materials selected were heat AAQ, the reference material; heat AAM, the material high in chromium and nickel; and heat AAO-1, the material containing only 0.22 per cent carbon. These materials were chosen because it was believed that their compositions would best encompass those normally produced commercially.

One specimen from each material was tested. The equipment employed consisted of a fused quartz tube and dial indicator very similar to that described in the "Metals Handbook."[4] The specimens were tested in the as-cast condition and the test cycles used consisted of:

TABLE X.—THERMAL EXPANSION AND CONTRACTION DATA FOR MATERIAL AAM.

Temperature Interval, deg Fahr	Average Linear Coefficients	
	Expansion, in. per in. per deg Fahr	Contraction, in. per in. per deg Fahr
80 to 200	6.5×10^{-6}	...
80 to 400	7.3	8.7×10^{-6}
80 to 600	8.7	8.9
80 to 800	9.4	9.3
80 to 1000	9.7	9.7
80 to 1200	10.1	9.9
80 to 1400	10.3	10.1
80 to 1600	10.5	10.4

Note.—Cycle of test:
1. Heating—room temperature to 1600 F
Total expansion....... 1.589 per cent
2. Holding—15¾ hr at 1600 F
Contraction produced at 1600 F........... 0.006 per cent
3. Cooling—1600 F to room temperature
Total change in length caused by test (contraction)............ 0.021 per cent

1. Heating from room temperature (about 80 F) to 1600 F.

2. Holding at 1600 F for about 16 hr.

3. Cooling from 1600 F to room temperature.

The heating and cooling rates were

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[4] "Fused-Quartz-Tube and Dial-Indicator Method," *Metals Handbook*, Am. Soc. Metals, p. 170 (1948).

approximately $4\frac{1}{2}$ F per min. No cooling curve was obtained from the specimen of heat AAO-1 because the thermocouple failed.

The heating and cooling curves obtained are given in Figs. 13, 14, and 15, and the average linear coefficients, and the expansions and contractions observed for the various portions of the test cycle, are listed in Tables IX, X, and XI.

Examination of these curves showed that very little change in the rate of expansion or contraction occurred within the interval from about 600 to 1600 F. Below 600 F, there was a slight change in the rate of expansion, particularly in the case of the specimen from heat AAM. This change is attributed to some peculiarity of the test rather than to some change in the specimen itself. The average linear coefficient of expansion over the range from about 80 to 1600 F was found to be approximately 10.5×10^{-6} in. per in. per deg Fahr for all three materials. This was slightly greater than that of the austenitic HH (26 per cent chromium - 12 per cent nickel) alloy (9.9×10^{-6} in. per in. per deg Fahr) and the HW (12 per cent chromium - 60 per cent nickel) alloy (8.6×10^{-6} in. per in. per deg Fahr).

TABLE XI.—THERMAL EXPANSION DATA FOR MATERIAL AAO-1.

Temperature Interval, deg Fahr	Average Linear Coefficient of Expansion, in. per in. per deg Fahr
80 to 200	9.1×10^{-6}
80 to 400	9.7
80 to 600	9.7
80 to 800	10.0
80 to 1000	10.2
80 to 1200	10.5
80 to 1400	10.7
80 to 1600	10.7

NOTE.—Cycle of test:

1. Heating—room temperature to 1600 F
   Total expansion .... 1.630 per cent
2. Holding—thermocouple failed; test discontinued.

CONCLUSIONS

1. The microstructure of the HF alloy features an austenitic matrix with carbon, in excess of that soluble in the matrix at solidification temperature, taking the form of eutectic carbides. Aging at moderate temperatures, that is, 1400 to 1600 F, causes secondary carbides to precipitate principally in the interdendritic areas. Extending the aging time to several thousand hours causes the secondary carbides to take the form of needles oriented along the major crystallographic planes of the matrix crystals. Heating at high temperatures, of the order of 1900 to 2150 F, causes the excess carbides to agglomerate and become spheroidized.

2. The microstructure may often contain a lamellar constituent. Its nature is not definitely known, though it is believed to contain chromium and carbon. Research by others suggests it also contains nitrogen. It was not possible to determine the influence of this constituent on the mechanical properties.

3. Metallographic examination and magnetic permeability tests indicate that the alloy can contain small amounts of ferrite, depending on composition and thermal history. A microstructural balance formula, similar to that developed by Gow and Harder for the HH alloy, is proposed. The formula uses nickel, chromium, and carbon as independent variables and is designed to distinguish those compositions which are entirely austenitic from those in which some ferrite may form.

4. The results indicate that sigma may sometimes form in the alloy on aging for long periods at intermediate temperatures such as 1400 to 1500 F. However, it appears that extreme deviation of the alloy from its mean specified composition, especially with respect to chromium

and carbon content, is required. In this connection, the results suggest that those compositions in which ferrite can form are susceptible to sigma formation. In one case the presence of sigma appeared to increase high-temperature strength. This was an interesting finding, but considerably more research would be required to evaluate its significance.

5. The data obtained on room-temperature tensile properties demonstrate the strengthening influence of carbon and nitrogen. They also show that these properties can be altered by aging, through the precipitation of secondary carbides. Though secondary carbide precipitation causes a reduction in ductility, substantial residual ductility exists in the metal.

6. Information obtained on short-time tensile properties at 1400 F suggests that nitrogen is a more effective strengthener than is carbon.

7. Data on stress-rupture properties obtained at 1200, 1400, and 1600 F confirm the strengthening influence of carbon. The effect of nitrogen could not be discerned.

8. The HF compositions investigated generally show excellent resistance to thermal fatigue. Susceptibility to thermal-fatigue cracking increases as the nickel or the carbon content increases, but it decreases when the excess carbides are agglomerated and spheroidized by a pretreatment at 1900 F. Susceptibility to thermal-fatigue cracking also decreases as temperature increases. The resistance of the HF alloy to thermal-fatigue cracking is far greater than that of the HH, HK, and HT grades.

9. The high-temperature strength of the HF alloy is indicated to be of the same order as that of the HH alloy containing nominally 26 per cent chromium and 12 per cent nickel and comparable carbon.

Acknowledgment:

The authors wish to express their gratitude to the Alloy Casting Inst. for permission to publish the results of this investigation. They also wish to acknowledge the important contributions made to the research by C. J. Slunder, Associate Division Consultant; J. H. Jackson, Manager, Department of Metallurgy; and O. E. Harder, Consultant, all of Battelle Memorial Inst.

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AN ALLOY EVALUATION TEST FOR CARBURIZATION RESISTANCE

By N. F. Spooner,[1] J. M. Thomas,[1] and L. Thomassen[2]

There has been an increasing use of carbonacious atmospheres in high-temperature furnaces, particularly those atmospheres with very high carburizing potentials. These atmospheres impose stringent requirements on metals and alloys used in furnace construction. Carbon pick-up can cause embrittlement, distortion, and lowered melting points. The carburization of heating element alloys in electric furnaces, where the elements are exposed to the carburizing gas, was the object of this study.

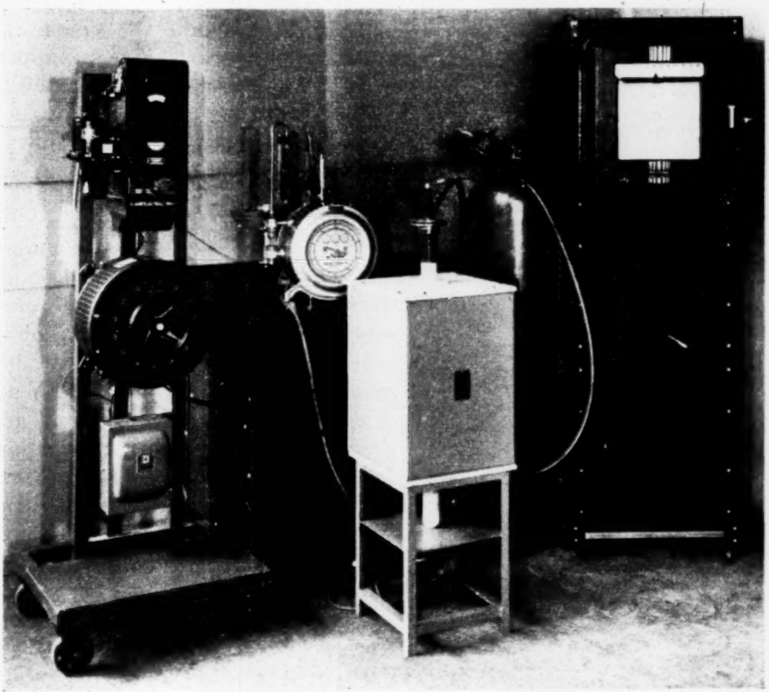

Fig. 1.—Photograph of Carburization Furnace and Control Panel.

Combined distortion and embrittlement can cause failures in heating elements because of expansion and contraction during heating cycles. Combined distortion, lowered melting points, and changes in electrical resistance can cause failures due to burnouts. If, for example, a furnace operating temperature is 500 F below the melting point of the heating element alloy, there can be four main factors contributing to burnout: (1) The elements themselves must operate at some temperature above the furnace temperature; temporary power overloads can increase this margin. (2) Distortion due to carburization may bring adjacent element turns closer together to form hot spots on the elements. (3) Carburization of certain heating element alloys causes an appreciable decrease in hot resistance; thus with the same line voltage the heating element will operate hotter than before carburization. The higher operating temperature may in turn accelerate the carburization. This condition will pyramid until the unit burns out. (4) In addition, severe carburization may lower the element alloy melting point by as much as 200 to 250 F. The latter three factors have caused rapid burnouts under conditions that without the carburizing gas would have resulted in long heating element life.

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[2] Professor of Chemical and Metallurgical Engineering, University of Michigan, Ann Arbor, Mich.

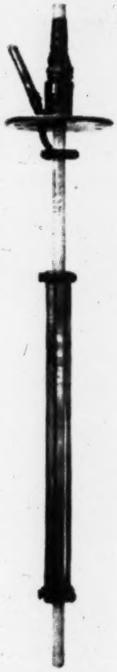

FIG. 2.—Photograph of Thermocouple Protection Tube and Specimen Assembly.

These failures can be reduced by: (1) better furnace temperature control, (2) better atmosphere control to maintain the minimum carburizing potential necessary, and (3) furnace element alloy changes to develop alloys with greater carburization resistance.

A laboratory furnace was equipped to expose test strips of various alloys to a carburizing atmosphere at temperatures up to 2150 F, and methods were developed to evaluate the effect of the exposure on various alloys. From this work it was possible to rapidly evaluate available heating element alloys and a large number of experimental alloys.

EQUIPMENT AND TEST PROCEDURE

Furnace and Test Chamber:

The furnace, with test chamber in place, and the furnace control panel are shown in Fig. 1. The furnace element was designed with a No. 10 alloy heating-element wound so as to produce a maximum temperature of 2150 F at the center of the test chamber, and also to produce a rather even thermal gradient to a temperature of approximately 1000 F near the ends of the test chamber. In this way, any one test will show the effect of the atmosphere used over a wide temperature range.

The specimen assembly is shown in Fig. 2. Five strip specimens ($\frac{1}{4}$ by 0.030 by 30 in. long) are included in each test. The test chamber is a high-temperature porcelain tube ($1\frac{5}{8}$ in. inside diameter by $1\frac{7}{8}$ in. outside diameter by 36 in. long). Gas enters the top of the test chamber at the rate of 0.8 cu ft per hr, and exits at the bottom. The gas inlet consists of a small steel tube bent in a circle with its center in the porcelain tube in Fig. 2. Properly sized holes for an even gas flow are distributed along the periphery of this tube.

Test Atmosphere:

The test atmosphere composition is nominally 20 per cent carbon monoxide,

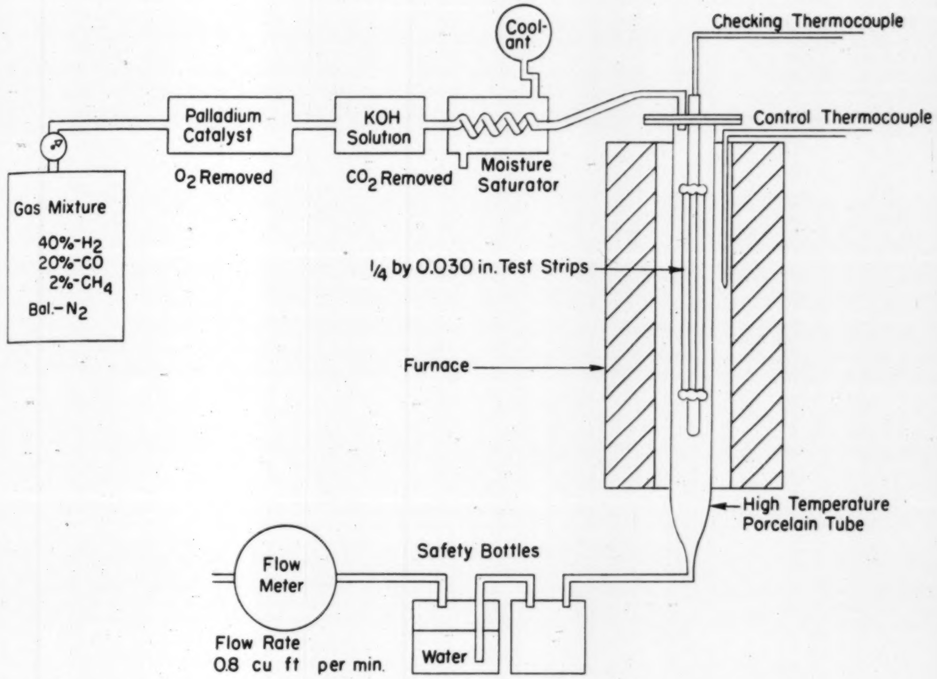
Cool-ant
Checking Thermocouple
Control Thermocouple
Palladium Catalyst
KOH Solution
Moisture Saturator
O$_2$ Removed
CO$_2$ Removed
Gas Mixture
40%-H$_2$
20%-CO
2%-CH$_4$
Bal.-N$_2$
1/4 by 0.030 in. Test Strips
Furnace
High Temperature Porcelain Tube
Safety Bottles
Flow Meter
Flow Rate
0.8 cu ft per min.
Water

FIG. 3.—Gas Train for Carburizing Test.

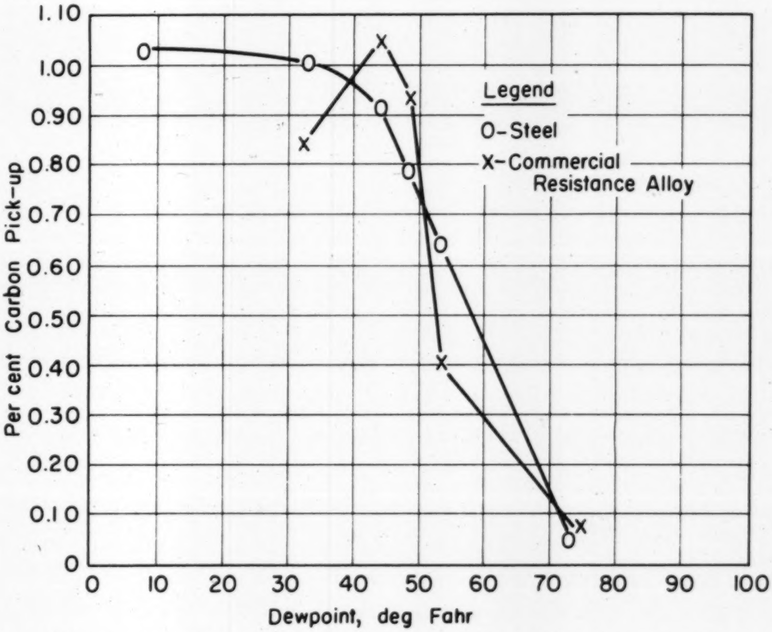

FIG. 4.—Effect of Dew Point on the Carburizing Potential of a Gas Containing 40 per cent Hydrogen, 20 per cent Cobalt, 2 per cent CH$_4$, Balance Nitrogen—2150 F.

40 per cent hydrogen, 2 per cent methane (CH_4), and the balance nitrogen. This mixture is purchased to order. The flow of the gas in use is shown in Fig. 3. A palladium catalyst eliminates any free oxygen, a potassium hydroxide solution eliminates any carbon dioxide, and a moisture saturator adjusts the dew point to the desired temperature, which may vary between 40 and 60 F depending on the exact composition of the gas. The temperature of the moisture saturator can be adjusted to ±1 F by the use of a reservoir of coolant, a thermostat, and a magnetic valve.

The objective has been to maintain an atmosphere in the test chamber which has a 1 per cent carbon potential to steel at 2150 F. The carbon potential of 1 per cent was chosen as this is the highest carbon potential normally used in industrial furnaces, and thus the test conditions should simulate the most severe commercial conditions that are likely to be encountered, that is, of course, if the atmosphere generating equipment is operating properly.

Although the conditions described above were set to attain a 1 per cent carbon potential, the final control has been to suspend a 2-in. length of $\frac{1}{4}$-in. wide 0.010-in. thick low-carbon steel strip in the test chamber, in the maximum temperature zone of 2150 F, and examine its microstructure after the test run. Weight measurements on the steel strip before and after the run give an approximate and fast indication of the carbon pickup.

The dew point control of the atmosphere is a very important factor. Figure 4 shows how the carbon potential to steel and to a commercial heating element material varies with the dew point of this atmosphere at a test temperature of 2150 F as measured with the equipment described.

Test Run Procedure:

The atmosphere gas flow is started before the furnace is turned on. The furnace takes about $1\frac{1}{2}$ hr to reach 2150 F and is held at 2150 F for 2 hr. The power is then turned off and the atmosphere changed to argon. The furnace cools to ambient temperature in about 1 hr, after which the argon is turned off, and the specimens removed. Longer test runs of up to 84 hr have shown that the 2-hr runs are a good indication of an alloy's susceptibility to carburization.

Sample Evaluation:

After exposure, the test specimens are examined for magnetic permeability (for some of the nonmagnetic alloy types, a change in permeability is one indication of carbon pickup), microstructure, and finally by carbon analysis of selected sections. The carbon analysis is the only final value of interest, but other checks may be correlated with analyses and are cheaper and faster evaluation methods.

Some idea as to the effect of carbon pickup on resistance can also be determined, but due to the temperature gradient the results can only be used relative to each other.

Test Results:

Representative test results for two alloys are shown below. These results illustrate the severity of the test, the correlation between short- and long-time tests, and the differences between alloy compositions which can be shown up by the test.

COMPARATIVE CARBON PICKUP IN THE TEST ATMOSPHERE.

	Carbon Pickup at 2150 F, per cent	
	2-hr run	84-hr run
Commercial alloy	0.80	1.70
Experimental alloy	0.10	0.45

A DIAMETER GAGE AND DYNAMOMETER FOR TRUE STRESS-STRAIN TENSION TESTS AT CONSTANT TRUE STRAIN RATE*

By G. W. Powell,[1] E. R. Marshall,[1] and W. A. Backofen[1]

Synopsis

A detailed design is presented for a diameter gage and dynamometer that may be used for tension testing to establish true stress-strain curves at constant true strain rate. To illustrate the use of the apparatus and the information that it can provide, typical data are included from tests on type 301 austenitic stainless steel at several strain rates at temperatures of 20 C and −196 C.

The importance of true stress-strain relationships to the subjects of metal strength and plasticity is soundly established. Such relationships are an essential part of fundamental studies of strain hardening and fracturing characteristics, of analyses of plastic working processes, and of evaluations of the effects of different processing histories on the mechanical behavior of metals.

The tension test provides one of the most convenient ways of establishing a curve relating true stress, σ, and true strain, ϵ, from yielding through fracture. It is clear from the definitions of σ and ϵ that both load and minimum cross-sectional area must be determined throughout a test. For a round test specimen,

$$\sigma = \frac{P}{A_i};\ \epsilon = \ln\frac{l_i}{l_o} \underset{\substack{\uparrow \\ (\text{because } A_o l_o = A_i l_i)}}{=} \ln\frac{A_o}{A_i} = 2\ln\frac{D_o}{D_i}\ldots(1)$$

where P, l, A, and D are load, length, area, and diameter, respectively, and the subscript "o" refers to initial dimensions, while "i" refers to dimensions at any instant during the test. Flow and fracturing characteristics may, under some conditions, be sensitive to the rate of straining; such dependence on strain rate is encountered as the testing temperature increases. It may also enter into the testing of structurally unstable materials like certain of the austenitic stainless steels which may undergo the strain and, to some extent, time-dependent martensitic transformation. Then true strain-rate control becomes desirable. The true strain rate is

$$\dot{\epsilon} = \frac{d\epsilon}{dt} = -\frac{2}{D}\frac{dD}{dt}$$

and if it is to be maintained at a constant value of $\dot{\epsilon}$, the diameter of the minimum cross-section must decrease with time according to the equation:

$$D_i = D_o e^{-\dot{\epsilon} t/2}\ldots\ldots\ldots\ldots(2)$$

Current procedures for establishing true stress-strain curves, even under conventional testing conditions, are

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* Presented at the Fifty-eighth Annual Meeting of the Society, June 26–July 1, 1955.

[1] Research Assistant and Assistant Professors, respectively, Department of Metallurgy, Metals Processing Laboratory, Massachusetts Institute of Technology, Cambridge, Mass.

moderately time consuming. For room temperature tests, a micrometer or dial-gage assembly is adequate for measuring the diameter needed to compute true stress and true strain. Gages are also described in the literature for tension testing at temperatures other than the ambient, in particular at low temperatures. In one, from the Bureau of Standards (**1**),[2] knife-edges contacting the test specimen are connected to a dial gage through mechanical linkage. In a second (**2**), the contacting knife-edges are attached to levers that actuate a differential transformer, the output of which is amplified and recorded autographically. Such gages, however, used in the ways described in the literature, are not the most suitable for imposing constant true strain rate, or any special strain rate program. High strain rates especially are extremely difficult to establish with any system requiring coordination of individual diameter measurements, made at more or less regular intervals of time, with testing machine crosshead speed (**3**). A need does exist, therefore, for a device of more general applicability that could make the determination and usage of tension true stress-strain relationships a less specialized and time-consuming undertaking.

The diameter gage and dynamometer described in this paper were constructed for the purpose of testing austenitic stainless steel at various constant true strain rates from approximately 6×10^{-3} to 600×10^{-3} per min and over a wide temperature range from room temperature downward. Among previously developed gages, the strongest resemblance is found to that described by Smith, Spangler, and Brick (**2**). However, the entire apparatus described here exhibits many convenient and unique features, such as: continuous visual recording of both load and diameter, simplicity, ruggedness, reasonable compactness, satisfactory accuracy, and sensitivity independent of temperature. The basic design is sufficiently versatile that application could be made to other testing conditions including additional automatic control, moderately high temperatures, bars of different sizes, and with some modification, even materials that develop elliptical cross-sections on necking. To facilitate such applications, design calculations are given in some detail. Also, for purposes of illustration, examples of test data are presented which reveal the effects of temperature and strain rate on the tensile flow and fracturing of an austenitic stainless steel.

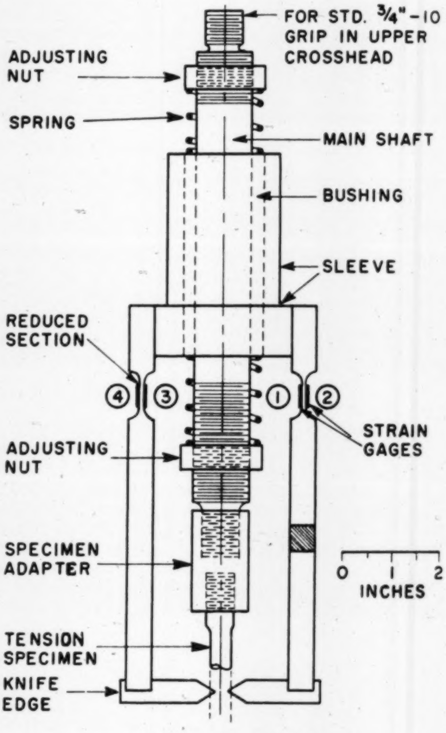

FIG. 1.—The Diameter Gage.

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[2] The boldface numbers in parentheses refer to the list of references appended to this paper, see p. 809.

Description of Apparatus

Figure 1 is a drawing of the diameter gage as it appears by viewing at right angles to the main shaft, or axis of tension; Fig. 2 similarly illustrates the coolant container with necessary adaptors and the dynamometer. The key feature of the diameter gage lies in the use of two identical cantilever arms fastened to a sleeve and aligned parallel to the main shaft. Machined into each arm near the upper fixed end is a reduced section, and on both sides of each section is mounted a resistance wire strain gage with its axis also parallel to the main shaft. Carefully fitted and screwed onto each arm at the lower free end is a knife-edge contactor, hardened to a Rockwell hardness, C scale, level of 62–64. At the start of the test, the cantilever arms are deflected outward from the rest position by introducing the tension specimen between the knife-edges. This deflection causes elastic bending strains in the reduced sections. Gages *1* and *3* are put in tension and *2* and *4* in compression. As load is applied to the tension specimen the diameter decreases, causing a proportionate decrease in the magnitude of the strains in the reduced sections. The change in strain in turn causes proportionate resistance changes in the four gages. All gages are connected in a Wheatstone-bridge circuit, shown schematically in Fig. 3.

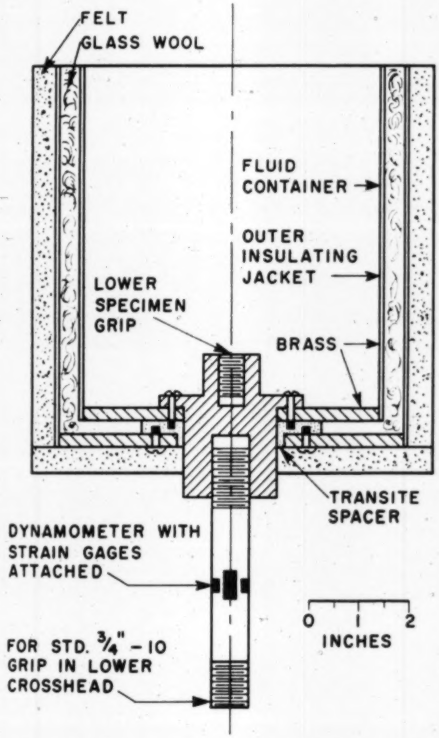

Fig. 2.—Coolant Container and Dynamometer.

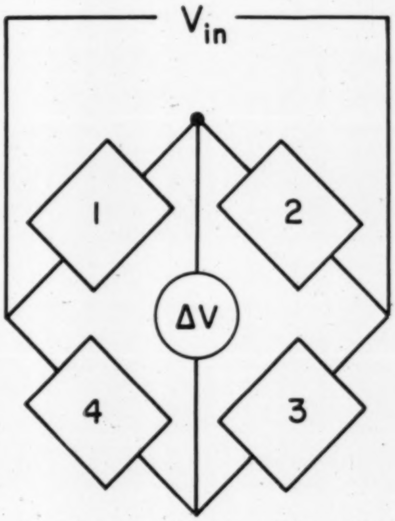

Fig. 3.—Schematic Wheatstone-Bridge Circuit.

With the gages joined together in such a bridge, it is not necessary that the axial alignment of the cantilever arms be perfect. Possibly both arms with their attached knife edges might be displaced or rotated slightly in the same direction by a small amount of cocking of the sleeve on the main shaft during a test. Should the displacement occur to the left in Fig. 1, for example, gage *2* which is strained in compression will undergo an additional increment of compressive strain, while gage *3* strained in tension will undergo a drop in tensile strain; the tensile strain in gage *1* will be increased and the compressive strain in gage *4* will be reduced. Therefore, since gages *2* and *3* (or *1* and *4*) will undergo strain and resistance changes of the same sign, the voltage output of the bridge due to this misalignment effect is zero.

Changes in gage resistance because of temperature change are also compensated for by the proximity, and thus essentially the same temperature, of gages *1* and *2* (or *3* and *4*). Therefore essentially equal resistance changes will be produced by any temperature changes, and, again because of the location of each pair in the bridge, the output due to this effect is likewise zero. The symmetric design of the apparatus also acts to insure uniform temperature distribution, further aiding in this type of compensation.

Calibration and Assembly:

The input and output of the strain-gage bridge are connected to a Sanborn (Twin-Viso Cardiette Model 60) strain gage amplifier and oscillograph. The deflection of the heated Sanborn stylus, recorded by burning a record on waxed rectilinear chart paper, is directly calibrated against the change in diameter, for a given instrument gain setting, by placing bars of various diameters (drill shanks) between the knife-edges. The response of the oscillograph was found to be linear with respect to change in diameter over the entire range employed. For the particular gain and attenuation settings that were used in testing, the slope of the stylus-deflection *versus* diameter calibration curve, or over-all sensitivity, was 250 millimeters of stylus deflection per inch of diameter change.

Calibration tests over a temperature range from room temperature downward showed the sensitivity to be essentially independent of the temperature at which the gages are functioning, a finding which agrees with that from previous work on the effect of subzero temperatures on the gage factor of resistance strain gages (4). Therefore, it is unnecessary to calibrate the diameter gage at each temperature of operation. In low-temperature testing, the strain gages are positioned about 2 in. above the level of the coolant in the container (Fig. 2); by attaching thermocouples to the reduced sections, the approximate steady-state temperature of the strain gages was found to be −120 C with the tension specimen immersed in boiling liquid nitrogen (−196 C).

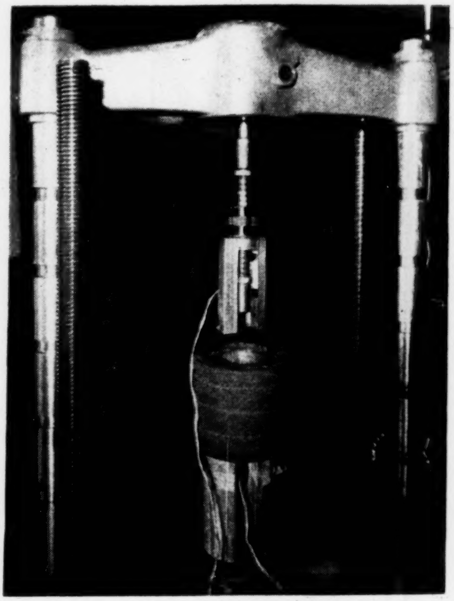

FIG. 4.—Diameter Gage and Dynamometer Installed in Hydraulic Testing Machine.

A photograph of the apparatus assembled in a hydraulic testing machine is shown in Fig. 4. In use, the strain gages were coated with a thin film of silicone high-vacuum grease and then covered with a glass-wool blanket taped to the cantilever arms. The arms are partially concealed in Fig. 4 by sheet-steel guards of hat-shaped cross-section which are provided with set screws to limit the outward motion of the arms during fracture of the specimen. Cross-bars attached to a bar linking the two guards also limit inward motion of the arms beyond the rest position.

The diameter of the tension specimen can be observed at any point along its gage length by grasping the sleeve and manually sliding the diameter gage up and down the main shaft. The bronze bushing within the sleeve is held securely through an interference fit with the sleeve, obtained by cooling in liquid nitrogen before being pressed into place. The two cantilever arms are rigidly fastened by pinning and bolting to flats machined on the enlarged lower end of the sleeve. The sleeve, with arms attached, slides freely on the main shaft so that once necking sets in the minimum diameter may be located and kept under constant observation wherever it might occur along the specimen. Springs placed around the main shaft above and below the sleeve suspend the knife-edges at some reasonably well-defined level or equilibrium position; then at fracture the sleeve cannot possibly fall or jump upward so far that excessive knife-edge displacement might damage the reduced sections through plastic bending. Also, an operator does not have to support the entire weight of the moving assembly throughout a test.

As the specimen is pulled, the neck and the location of the minimum diameter move downward relative to the upper specimen adaptor. By turning the uppermost adjusting nut downward, the equilibrium position of the sleeve is displaced downward. Thus the knife-edges may be maintained close to the minimum section of the specimen throughout the entire test by moving the adjusting nut as needed.

The load applied to the tension specimen is also measured with four electric wire-resistance strain gages mounted in a Wheatstone-bridge circuit on a cylindrical steel bar. The dynamometer and the method of incorporating it in the apparatus are illustrated in Fig. 2. Referring to the standard bridge diagram in Fig. 3, gages *1* and *3* are aligned parallel and gages *2* and *4* perpendicular to the axis of tension to take advantage of the Poisson effect and obtain the maximum possible output from the bridge. The bridge output was recorded simultaneously with that corresponding to the specimen diameter on the Sanborn two-channel chart; from a calibration of the dynamometer in the testing machine, the chart record could be converted to tensile load.

DESIGN OF THE DIAMETER GAGE

A standard subsize test specimen of 0.375-in. diameter was chosen for testing. It was next decided that it should be possible to measure a maximum diameter change corresponding to a reduction of area of 75 per cent. The diameter at the end of the test is then 0.185 in. so that $\Delta D_{\max}$, the maximum diameter change to be provided for, is approximately 0.20 in.

The over-all or total sensitivity, S_t, required for the diameter gage-Wheatstone bridge-Sanborn system can now be calculated. Sensitivity, S, is defined by the general relation (5)

$$S = \frac{\text{output increment}}{\text{input increment}} \quad \text{(3)}$$

Thus S_t is given by

$$S_t = \frac{\Delta X}{\Delta D} \quad \text{(4)}$$

where:

ΔX = stylus deflection in millimeters, and

ΔD = change in diameter of the tension specimen in inches.

It is desirable for ease of interpretation to use the full chart width of 50 mm for the maximum diameter change of 0.20 in. Therefore, the required sensitivity from Eq 4 is

$$S_t = \frac{\Delta X_{\max}}{\Delta D_{\max}} = \frac{50}{0.2} = 250 \text{ mm per in.}$$

Each component of the system also has a sensitivity as defined by Eq 3:

$$S_s = \text{Sanborn sensitivity} = \frac{\Delta X}{\Delta V} \quad \ldots (5)$$

$$S_b = \text{bridge sensitivity} = \frac{\Delta V}{\Delta e} \quad \ldots\ldots (6)$$

$$S_d = \text{diameter gage sensitivity} = \frac{\Delta e}{\Delta D} \quad \ldots (7)$$

where:

ΔV = change in output voltage of the bridge circuit, and

Δe = change in elastic strain in the reduced section of the cantilever arms (or in each of the strain gages in the 4-gage bridge).

(Other terms have been defined above.) From Eqs 4, 5, 6, and 7, the total sensitivity is seen to be equal to the product of the component sensitivities:

$$S_t = S_s \times S_b \times S_d \quad \ldots\ldots\ldots (8)$$

The maximum S_d can now be determined from the maximum permissible strain, $\Delta e_{\max}$, in the reduced section of the cantilever arms and $\Delta D_{\max}$ of 0.20 in. The $\Delta e_{\max}$ is set by the endurance limit of the SR-4 type A7 strain gages employed, rather than by the arms which were made of 4140 steel hardened and tempered to Rockwell C 30 prior to machining. In terms of strain, this limit is 0.001 in. per in. (6). But since a gage will have a long useful life at twice this strain (6), a considerable safety factor is introduced. Thus from Eq 7,

$$S_d = \frac{\Delta e_{\max}}{\Delta D_{\max}} = \frac{0.001}{0.2} = 0.005 \text{ in. per in.}^2$$

With the sensitivity of the diameter gage determined, arm dimensions can be specified which will give this sensitivity and at the same time meet the additional requirements of a low contact (horizontal) force, F_c, between the knife-edges and tension specimen. As shown in the Appendix, the change in strain, Δe, in the reduced section is given as a function of the change in the contact force, ΔF_c, and the arm dimensions, illustrated in Fig. 5, by

$$\Delta e \cong \frac{6L}{Ebh^2} \Delta F_c \quad \ldots\ldots\ldots\ldots (9)$$

where:

L = arm length,

E = Young's modulus for the steel arms of 30×10^6 psi,

b = width of the reduced section (perpendicular to the plane of the drawing in Fig. 5), and

h = thickness of the reduced section.

It is also shown in the Appendix how the horizontal knife-edge deflection, $\delta = (\frac{1}{2})\Delta D$, can be obtained in terms of ΔF_c and arm dimensions by strain-energy methods:

$$\Delta D = 2\delta \cong \frac{24L^2l}{Ebh^3} \Delta F_c \quad \ldots\ldots\ldots (10)$$

where l is the length of the reduced section. Dividing Eq 9 by Eq 10 yields the sensitivity of the diameter gage as a function of h, L, and l:

$$S_d = \frac{\Delta e}{\Delta D} = \frac{h}{4Ll} \quad \ldots\ldots\ldots (11)$$

To achieve the maximum S_d of 0.005 in. per in. that was calculated above, the dimensions chosen were $h = 0.060$ in., $L = 6$ in., and $l = 0.5$ in.

The contact force will be a maximum at the beginning of a test when the knife-edge deflection is greatest. To limit abrasion of the test specimen by the knife-edge contactors, as well as for ease of motion of the diameter gage, it was decided that this maximum value should be of the order of 1 lb. By making $b = 0.50$ in., the contact-force requirement can be met reasonably well. Substituting $\Delta D = 0.20$ in. along with all values now specified for L, l, h, and b into Eq 10 shows that the contact force when a test starts will be about 1.5 lb.

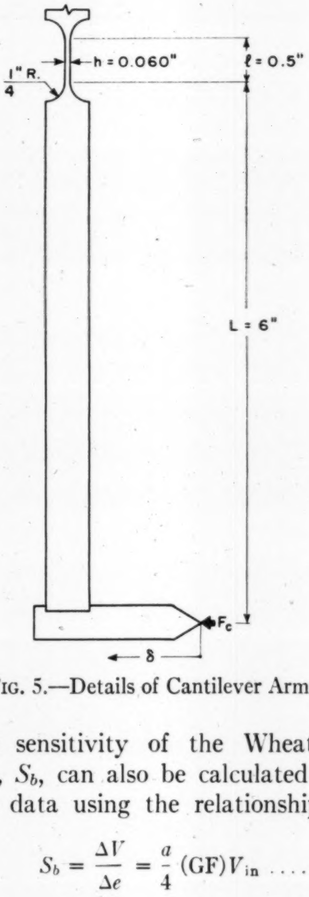

Fig. 5.—Details of Cantilever Arm.

The sensitivity of the Wheatstone bridge, S_b, can also be calculated from design data using the relationship (6):

$$S_b = \frac{\Delta V}{\Delta e} = \frac{a}{4}\,(\text{GF})V_{\text{in}} \;\ldots\ldots\; (12)$$

where:

a = number of arms of the bridge with active resistance; $a = 4$ in the present design,

GF = gage factor of the strain gages as determined by the manufacturer; GF = 1.94 for the SR-4, 120 ohm, type A7 gages used, and

V_{in} = input voltage to the bridge, supplied by Sanborn unit (which also supplies amplification of output); $V_{\text{in}} = 3.15$ v for the 4-arm bridge of 120-ohm resistance gages.

Upon substituting the specific values in Eq 12, it is found that $S_b = 6.12$ v.[3]

The sensitivity at which the Sanborn amplifier must be operated, S_s of Eqs 5 and 8, to meet the total required sensitivity, S_t, of 250 mm per in. can now be determined since all other component sensitivities are established. S_s is the only unknown in Eq 8 which provides the value of

$$S_s = \frac{(250)}{(0.005)(6.12)} = 8.18 \times 10^3 \text{ mm per v}$$

This operating value is considerably less than the maximum obtainable with the amplifier, which may be calculated from the stylus deflection at full gain and unit attenuation when the 1 megohm calibration resistor is shunted across an arm of the bridge (7). The output-voltage change, ΔV_c, for an initially balanced bridge due to the calibration resistor is

$$\Delta V_c = \left(\frac{V_{\text{in}}}{4}\right)\left(\frac{R}{R_c}\right) \;\ldots\ldots\ldots\; (13)$$

where:

V_{in} = input voltage of 3.15,

R = gage resistance of 120 ohms, and

R_c = calibration resistance of 10^6 ohms.

Therefore ΔV_c is 9.45×10^{-5} v. The corresponding stylus deflection was found to be 22 mm, so that Eq 5 shows the maximum obtainable S_s to be

$$(S_s)_{\max} = \frac{\Delta X}{\Delta V} = \frac{22}{9.45 \times 10^{-5}}$$
$$= 2.33 \times 10^5 \text{ mm per v}$$

---

[3] It is assumed that the bridge is very nearly balanced at all times. Once the initial balance is obtained, elastic strains in the gages as large as the fatigue limit are still sufficiently small to keep S_b a constant.

Because of such a difference between this value and the much lower required operating sensitivity of only 8.18×10^3 mm per v, it was possible to operate the Sanborn unit with an attenuation factor of 20, at a little less than three fourths full gain, and still obtain $S_t = 250$ mm per in. These operating conditions were especially desirable both for good amplifier stability and elimination of pickup and background noise.

The accuracy of the design calculations may be evaluated by comparing calculated and experimentally determined values of the maximum over-all sensitivity. Substituting $(S_s)_{\text{max}} = 2.33 \times 10^5$ mm per v and the design values of S_b and S_d in Eq 8 gives for the maximum calculated S_t a value of 7150 mm per in. By experimental calibration, as explained under Description of Apparatus, the maximum over-all sensitivity for *full* gain and *unit* attenuation was found to be 6880 mm per in. Thus the difference between the results of calculation and experiment proved to be but 4 per cent.

TEST PROCEDURE

To perform a test incorporating any particular strain-rate program, it is necessary to prepare the Sanborn chart in advance with a curve relating the required stylus deflection (representing diameter change) to the chart length (representing time). A constant true-strain rate requires the diameter-time variation given by Eq 2. For such a test, Eq 2 is rewritten as

$$\Delta D = D_o - D_i = 1 - e^{-\dot{\epsilon}t/2} \quad \ldots\ldots (14)$$

Then substituting $\Delta D = \Delta X/S_t$ from Eq 4 gives

$$\Delta X = S_t D_o(1 - e^{-\dot{\epsilon}t/2}) \quad \ldots\ldots (15)$$

The chart length, c, traversed in time, t, for a chart speed of v_c is

$$c = v_c t \quad \ldots\ldots (16)$$

Now substituting $t = c/v_c$ in Eq 15 gives the final equation needed for the chart preparation:

$$\Delta X = S_t D_o(1 - e^{-\dot{\epsilon}c/2v_c}) \quad \ldots\ldots (17)$$

Figure 6 shows the chart appearance after a constant true strain rate test. The heavily drawn, smooth curve for the channel recording diameter change in the upper part of the figure was prepared before the test began, and represents the variation of ΔX with c according to Eq 17 that is required for the conditions:

$\dot{\epsilon}$ = constant at 180×10^{-3} per mm,
v_c = constant at 30 mm per sec,
D_o = 0.375 in., and
S_t = 250 mm per in.

When a number of tests are to be carried out for a reasonably limited range of conditions, the use of templates in drawing the ΔX *versus* c curves greatly expedites the testing program.

In conducting a test, the diameter gage, coolant container, and dynamometer are installed in the testing machine. Then the 0.375-in. diameter tension specimen, reduced about 0.004 in. on the diameter toward the center of the gage length to insure necking at this point, is screwed into the upper and lower grips. The knife-edge contactors are moved up or down by means of the adjusting nuts so that they are held in equilibrium against the spring pressure over the slightly reduced diameter. Next, the liquid coolant is poured into the container to a level about 3 in. above the top of the specimen, and, by additions, this is maintained within about ½ in. throughout the test. A thermocouple is attached to one arm of the diameter gage just below the reduced section to determine when the temperature of the arm, and therefore of the strain gages as well, has reached equilibrium. With the cantilever arms deflected by the maximum amount and with no load on the test specimen, the bridges are now balanced with the Sanborn unit, and the stylus for each channel brought to a zero-deflection level. Precise adjustment of instrument gain is particularly important for the diameter-gage channel; S_t must equal 250 mm per in. This is accomplished through control of the deflection produced by introducing the calibration resistor. The height of the deflection from the calibration resistor corresponding to $S_t = 250$ mm per in. is determined precisely during the initial calibration of the diameter gage with drill shanks that yield this value of S_t. Therefore, adjusting the gain control to reproduce that deflection height in each test insures that $S_t = 250$ mm per in. The gain and attenuation step for the dynamometer circuit are adjusted so that the stylus deflection corresponding to the expected ultimate load will be confined to the scaled part of the chart paper. Finally the test specimen is preloaded slightly with several hundred pounds to take up any slack in the testing rig.

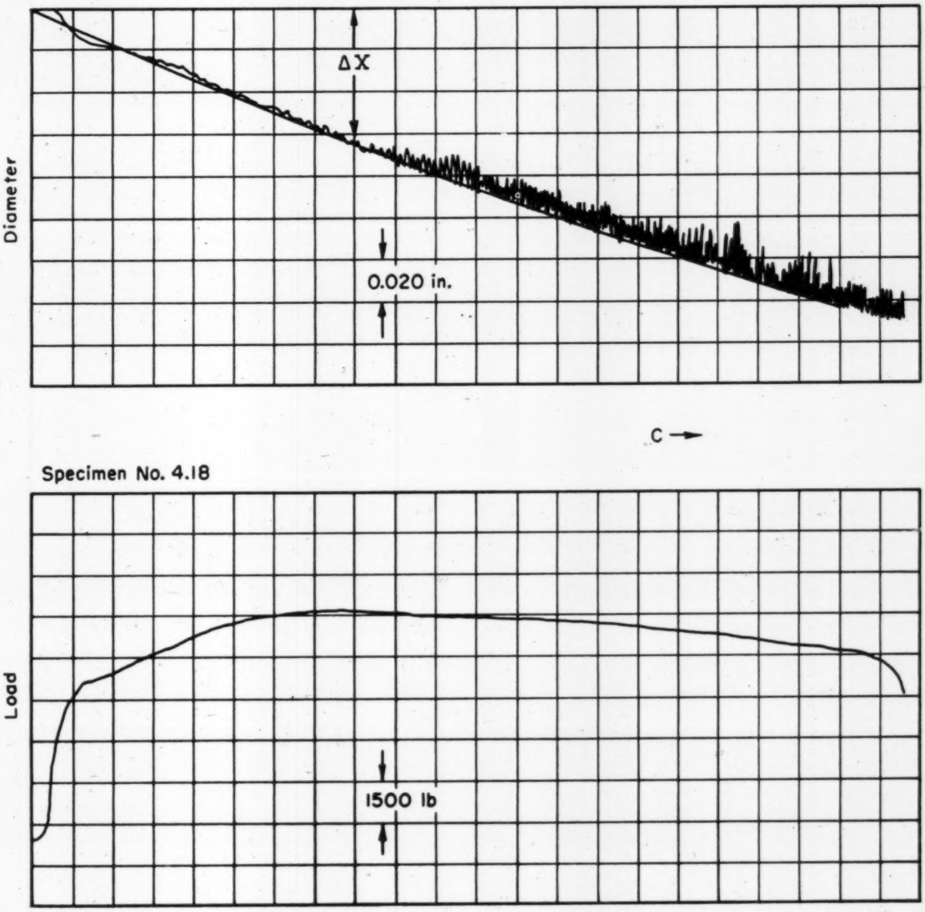

FIG. 6.—Oscillograph Chart Showing Diameter and Load Variations.

Two people are required to carry out a constant true strain rate test. One moves the diameter gage up and down, traversing the knife-edge contactors over the minimum section, and occasionally lowers the adjusting nuts as the minimum section (which later becomes the neck) moves downward with respect to the upper grip. As the test progresses, the diameter at the minimum section becomes smaller and the deflection in the cantilever arms becomes less. Therefore the amount of unbalance in the diameter-gage bridge circuit increases and so does the stylus deflection measuring diameter change. But the diameter-gage operator is constantly traversing the minimum section so that the stylus deflection varies from a minimum above the point where the diameter is smallest to a maximum at this point and to a minimum again as the knife-edges are moved still farther down the gage length. At the beginning of the test, the distance traversed was an inch or so, but once necking set in, the distance was little more than $\frac{1}{8}$ in. As a consequence of this motion, the stylus tracing has a cyclic, somewhat saw-tooth appearance, with the locus of maximum deflection from the starting position representing the variation of the minimum specimen diameter throughout a test. The testing machine operator regulates the hydraulic loading valve so that the maximum stylus deflection is kept as close as possible to the prepared ΔX *versus* c curve from Eq 17. Figure 6 shows how closely the prepared curve can be followed with the maxima of the jagged stylus-deflection curve during a relatively fast test. Simultaneously with the development of this curve, the variation of load on the specimen is being recorded on the chart from the other channel.

A true stress-strain curve is prepared best with these data by first constructing from the chart, using appropriate scale factors, a plot relating load and minimum diameter. Then true stress and true strain are readily calculated with Eq 1. Should it be desired to adjust the average true stress computed in this fashion to compensate for the stress triaxiality during necking, use might be made of the empirical relationship offered by Bridgman for correlating his correction factor with true strain (**8, 9**).

TYPICAL TEST RESULTS

To illustrate what may be accomplished with the diameter gage and dynamometer, a few data are presented and discussed very briefly.

True stress-strain curves from room temperature tests on type 301 (austenitic) stainless steel at various constant true strain rates are plotted in Fig. 7. As $\dot{\epsilon}$ increases from 6×10^{-3} to 60×10^{-3} per min, the curve is displaced upward slightly in keeping with the commonly observed effect of increasing strain rate on resistance to deformation. But as $\dot{\epsilon}$ increases further from 180×10^{-3} to 600×10^{-3} per min, the curve falls until that for 600×10^{-3} per min is little higher than that for 6×10^{-3} per min. At the higher strain rates, the test specimen undoubtedly became heated to some temperature above room temperature even though all such tests were performed while the coolant container was filled with water. Therefore a temperature rise during testing causing a lowering of strength level might be held at least partly responsible for these findings. Of additional significance, however, is the effect of strain rate on the structural transformation from austenite, γ, to ferrite, α (or martensite, as the transformation product may be called) that may contribute to the plastic deformation of many of the steels from the class represented by type 301. For the type 301, greater amounts of the strength-producing transformation occur at $\dot{\epsilon} = 60 \times 10^{-3}$ per min than at $\dot{\epsilon} = 600 \times 10^{-3}$ per min. This fact also contributes to the explanation of the trend observed in Fig. 7, and may in turn be related to the greater temperature rise that must be

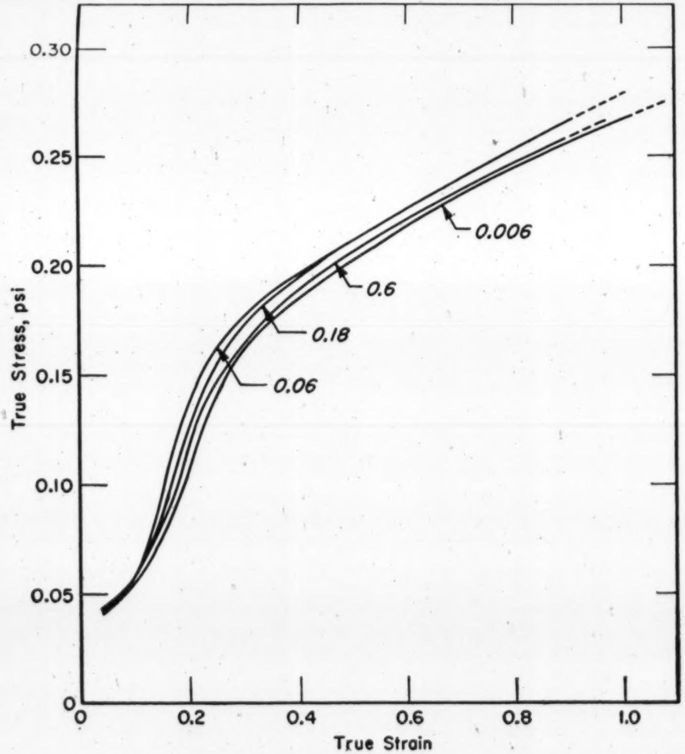

FIG. 7.—True Stress-Strain Curves from Room Temperature Tension Testing of Type 301 Austenitic Stainless Steel at Various Constant True Strain Rates.

The strain rates noted on the curves have units of min^{-1}.

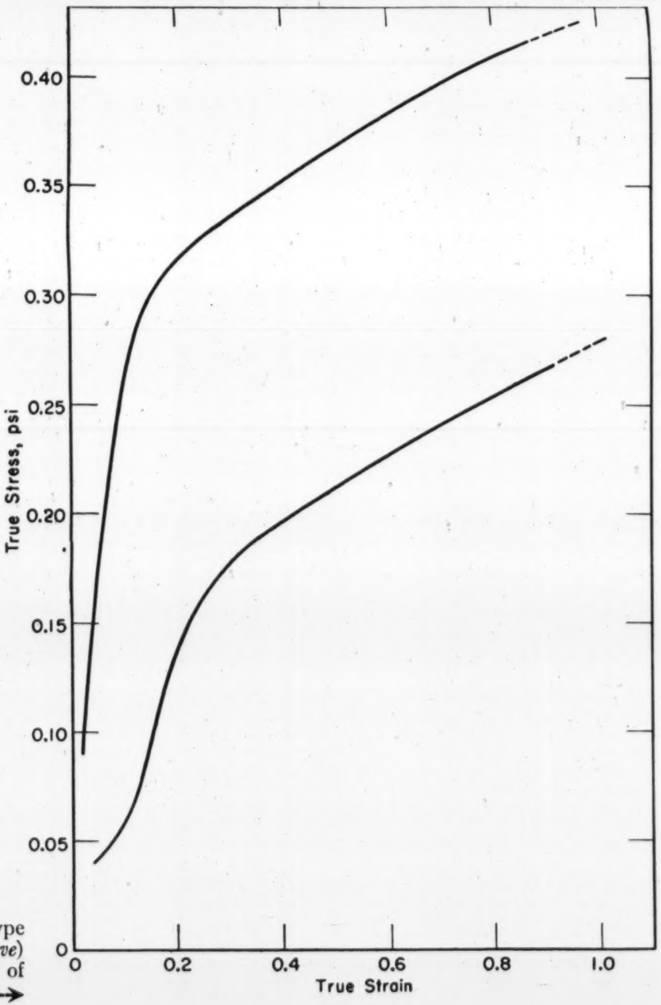

FIG. 8.—True Stress-Strain Curves from Tension Testing of Type 301 Austenitic Stainless Steel at Room Temperature (*Lower Curve*) and −196 C (*Upper Curve*) and at a Constant True Strain Rate of 60×10^{-3} min^{-1}.

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associated with the higher strain rate. Regardless of the explanation, however, it is clear that any detailed study of the strain-hardening characteristics of these materials will benefit from careful strain-rate control.

Two true stress-strain curves are shown in Fig. 8 to illustrate the effect of testing temperature on strain hardening. Both were determined with $\dot{\epsilon} = 60 \times 10^{-3}$ per min but at room temperature for the lower curve and at the temperature of boiling liquid nitrogen (-196 C) for the upper. Much of the explanation of the considerably greater strength at the lower temperature is found in the more extensive transformation at this temperature. It is clear that very high strength levels may be reached under such conditions. Differences in transformation tendencies at the various test temperatures also help in explaining the different appearances of the stress-strain curves. Although not apparent from the curves in Fig. 8, it was observed that the uniform strain preceding the onset of necking at 20 C was 0.36; at -196 C, however, the uniform strain was halved to 0.18 when the maximum load was reached and necking set in.

Acknowledgment:

The authors are grateful to the Office of Naval Research for its support of the program in which this instrumentation was developed.

APPENDIX

DERIVATION OF THE RELATIONSHIP BETWEEN CONTACT FORCE AND KNIFE-EDGE DISPLACEMENT

The strain increment, Δe, at the surface of the reduced section of the cantilever arms due to bending is related to the stress increment and Young's modulus by

$$\Delta e = \Delta\sigma / E \qquad \text{(18)}$$

From elastic beam theory, the stress increment is given by

$$\Delta\sigma = \frac{\Delta M (h/2)}{I} \qquad \text{(19)}$$

where:

ΔM = change in bending moment due to deflection of the knife-edges,

h = thickness of the reduced section (see Fig. 5), and

I = moment of inertia of rectangular cross-sectional area of the reduced section about the neutral axis of bending.

And for a rectangular cross-section

$$I = \frac{bh^3}{12} \qquad \text{(20)}$$

where:

b = width of the reduced section.

Also, the increment of bending moment in the reduced section is given to a good degree of approximation by

$$\Delta M \cong L \cdot \Delta F_c \qquad \text{(21)}$$

where:

L = arm length (see Fig. 5), and

ΔF_c = force increment on the knife-edge.

Equation 21 is but an approximation because there is a bending moment gradient along the reduced section which is negligible only when L is considerably greater than l, the length of the reduced section (see Fig. 5). Its use is justified in the present design where $L/l = 12$. Combining Eqs 19, 20, and 21 and then substituting in Eq 18 yields Eq 9 from the text.

The deflection of one of the knife edges can be related to the increment of elastic strain energy, ΔU, stored in the reduced section, and ΔF_c by

$$\Delta U = \tfrac{1}{2}\delta \cdot \Delta F_c \qquad \text{(22)}$$

The strain energy increment of bending is given by (**10**)

$$\Delta U = \int_0^l \frac{(\Delta M)^2\, dl}{2EI} \qquad (23)$$

Now substituting Eq 21 in Eq 23 and integrating (remembering ΔM is very nearly constant along l) gives

$$\Delta U = \frac{(\Delta F_c)^2 L^2 l}{2EI} \qquad (24)$$

Finally, by combining Eqs 20, 22, and 24, Eq 10 from the text results:

$$\Delta D = 2\delta \cong \frac{24L^2 l}{Ebh^3}\,\Delta F_c \qquad (10)$$

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MECHANICAL PROPERTIES OF A MAGNESIUM ALLOY UNDER BIAXIAL TENSION AT LOW TEMPERATURES*

By Edward Paxson,[1] Joseph Marin,[2] and L. W. Hu[2]

Synopsis

This paper describes an experimental investigation on the mechanical properties of a magnesium alloy FS1-H24. The properties in both simple tension and biaxial tension were obtained at various low temperatures. Biaxial tensile properties were determined by the bulge-type test, using a thin circular plate clamped at the edges and subjected to lateral hydrostatic pressures. The test results showed that the experimental plastic stress-strain relations can be expressed by the simple flow theory. The ductility of the magnesium alloy tested was found to be considerably less under biaxial tension than under simple tension. The modulus of elasticity in simple tension was found to vary according to the relation $E = Ae^{Q/RT}$, where E is the modulus of elasticity, T is the absolute temperature, e is the base for natural logarithms and A, Q, and R are material constants.

In the bulge test, a thin circular plate clamped at the edges is subjected to a lateral pressure. Under this type of loading, plastic stress-strain relations and mechanical properties can be obtained for materials under biaxial tensile stresses. A number of investigations have been conducted at room temperature using the bulge-type test. Some of these investigations are described elsewhere (**1** to **8**)[3]. Studies on the effect of low temperatures on the biaxial properties and plastic stress-strain relations of metals have been made using tubular specimens of circular cross-sections subjected to internal pressure and axial tension (**9**, **10**). Low-temperature biaxial stress properties were also determined using thin-walled spherical shells subjected to internal pressures (**11**). In this investigation, low-temperature biaxial mechanical properties of a magnesium alloy were determined using the bulge-type test.

Test Equipment and Procedure

Material Tested and Specimens:

The material tested was an FS1-H24 magnesium alloy. Its chemical composition, in addition to magnesium and normal impurities, consisted of 2.5 to 3.5 per cent aluminum, 0.20 per cent manganese, and 0.7 to 1.3 per cent zinc. The nominal mechanical properties, as reported by the manufacturer, are: Ten-

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[2] Professor and Head, Department of Engineering Mechanics, and Assistant Professor of Engineering Research, respectively, The Pennsylvania State University, University Park, Pa.

[3] The boldface numbers in parentheses refer to the list of references appended to this paper, see p. 821.

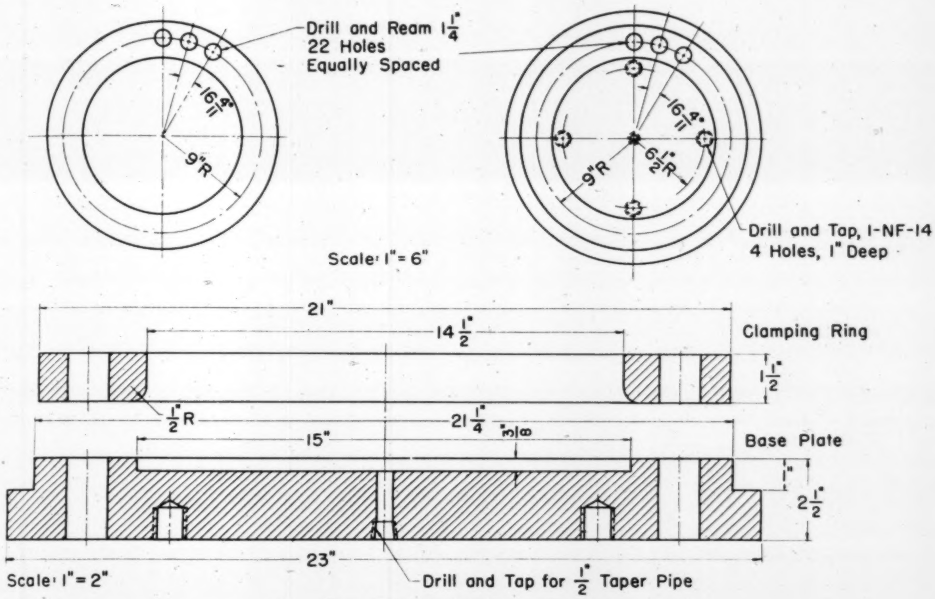
Drill and Ream 1 1/4"
22 Holes
Equally Spaced
16 4°/11
9"R
16 4°/11
6 1/2"R
9"R
Drill and Tap, 1-NF-14
4 Holes, 1" Deep
Scale: 1" = 6"
21"
14 1/2"
Clamping Ring
1 1/2"
1/2"R
21 1/4"
3/8"
15"
Base Plate
1"
2 1/2"
23"
Scale: 1" = 2"
Drill and Tap for 1/2" Taper Pipe

Fig. 1.—Circular Bulge Tester.

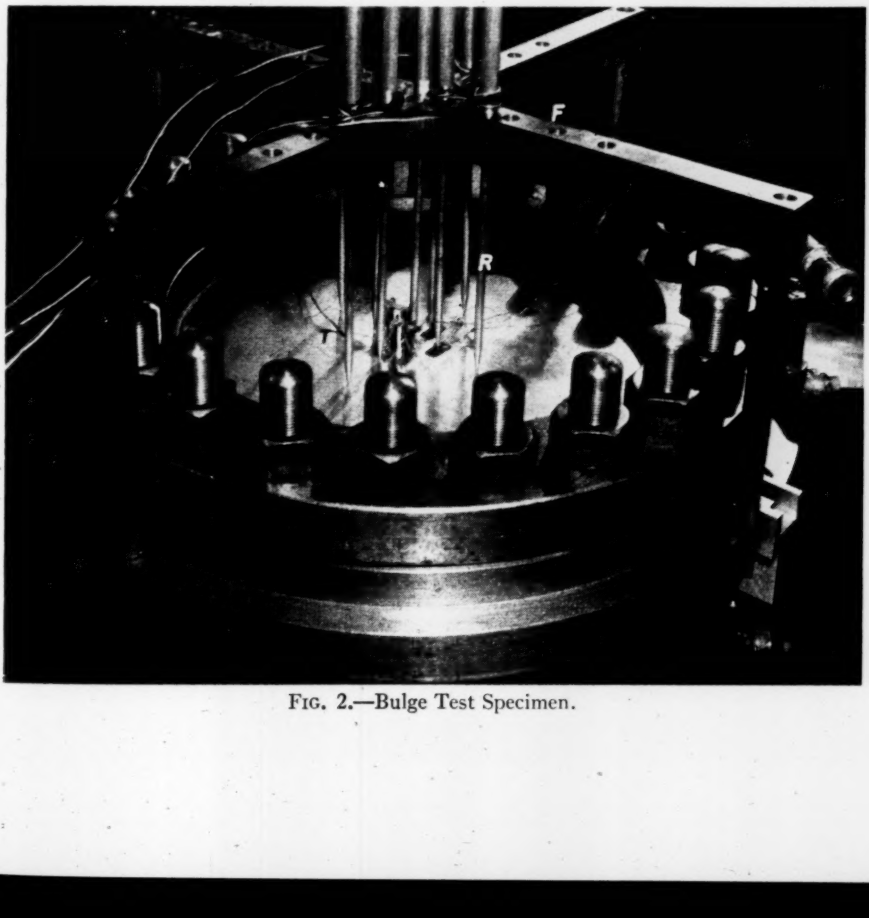

Fig. 2.—Bulge Test Specimen.

sile strength, 42,600 psi; yield strength, 32,600 psi; and total elongation, 16.5 per cent. The material was received in the form of sheets 4 by 12 ft by 0.04 in. thick. The bulge test specimens consisted of circular plates 21 in. in diameter. No machining of any sort was required except that 22 holes were punched near the circumference of each specimen to allow for $1\frac{1}{4}$-in clamping bolts. Tension specimens were machined from the sheets so that the reduced section had a width of $\frac{1}{2}$ in., a thickness of 0.04 in., and a gage length of 3 in.

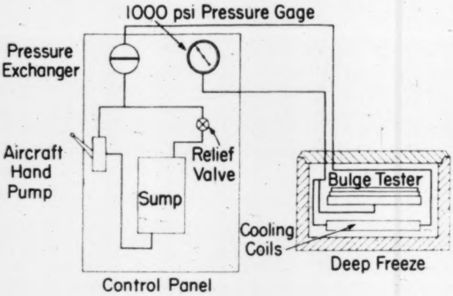
1000 psi Pressure Gage
Pressure Exchanger
Aircraft Hand Pump
Relief Valve
Sump
Bulge Tester
Cooling Coils
Deep Freeze
Control Panel

FIG. 3.—Schematic Diagram of Hydraulic System.

Bulge Test Equipment:

The test apparatus consisted of bulge test equipment for testing the circular plates under combined stresses and tension test equipment for conducting control tests in tension. In addition, a deep freeze unit for applying low temperatures was used.

The basic parts of the bulge tester consisted of a heavy base plate and a clamping ring, as shown in Fig. 1. The specimen was fastened between the plate and ring with bolts, as shown in Fig. 2. A $\frac{1}{2}$-in. radius on the inside edge of the clamping ring was provided in order to prevent failure at the edge of the specimen by either shear or bending. During trial tests the $\frac{1}{2}$-in. radius was increased by placing four rings of soft, thin aluminum between the specimen and the clamping ring in the vicinity of the radius. These rings became deformed around the radius as the specimen was deformed.

The hydraulic pressure in the bulge tester was produced by the pressure system shown in Fig. 3. Ordinary motor oil was pumped by an aircraft hand pump into a chamber that transferred the pressure to a second liquid. For room-temperature tests, the motor oil was used as the second liquid. For low-temperature tests, a Univis J-43 hydraulic fluid was used. The transfer chamber was connected to the bulge tester by using cooling coils in the same low-temperature chamber as the tester. The pressure of the liquid in the tester was measured by a 0 to 1000-psi Bourdon pressure gage. For the final tests a 0 to 60-psi pressure gage was also used.

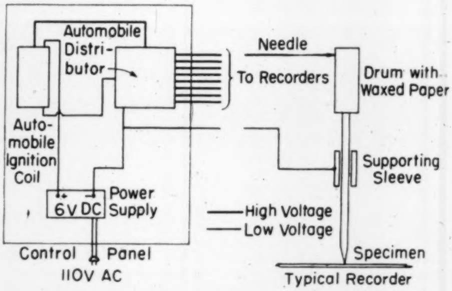
Automobile Distributor
Automobile Ignition Coil
6V DC
Power Supply
Control Panel
110V AC
Needle
To Recorders
Drum with Waxed Paper
Supporting Sleeve
High Voltage
Low Voltage
Specimen
Typical Recorder

FIG. 4.—Schematic Diagram of Spark Recording Apparatus.

A special apparatus (Fig. 4), called a "spark recorder," was developed for measuring the deflection of the specimen at various positions. The basic unit consisted of a frame, *F*, guiding nine vertical rods, *R*, that rested on the specimen, as shown in Fig. 2. A piece of waxed paper was attached to each rod near the top. A needle was attached to the frame so that a spark could be shot through the waxed paper to the rod at any time as the rod rose with the specimen. The deflection of the bulge was determined by measuring, using a microscope, the distance between the holes in the waxed paper (Fig. 5).

Strains were determined near the center of the bulge by direct measurement with electric strain gages. SR-4 type PA-3 gages were tried with very little success. These gages measure strains up to at least 10 per cent in simple tension. That they failed at very low strain values on the bulge specimens might be attributed to the combined state of stress and the fact that the specimen did not remain flat during the test. A clip-type gage (Fig. 6), using SR-4 gages as the sensitive elements, was later used with fair success for measuring the strains. The primary problem with the clip gages was one of mounting. The method finally developed utilized rubber bands and hooks glued to the specimen to hold the gage down (Fig. 2). For the final tests, ordinary SR-4 gages (gages that measure strains to approximately 2 per cent in simple tension) were used in conjunction with the clip gages. The SR-4 gages were employed to calibrate the clip gages in the elastic range. Independent calibration tests on the clip gages showed that the relation between the strain applied and the strain measured was essentially linear.

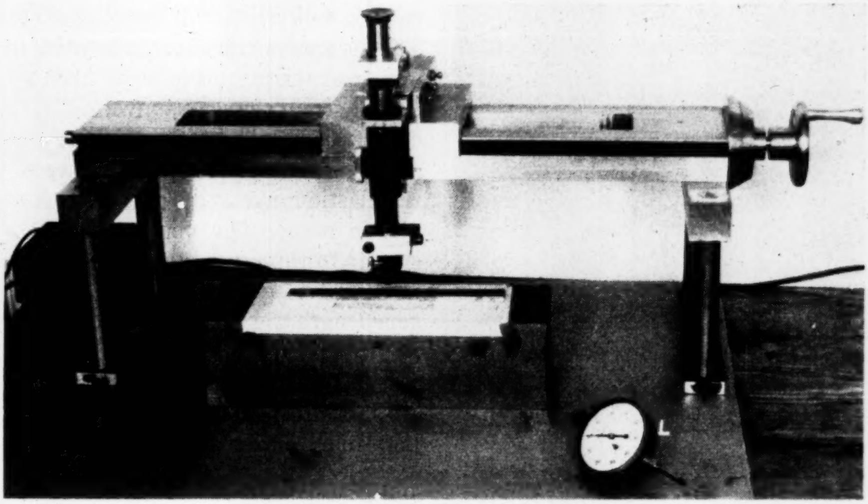

Fig. 5.—Deflection Measuring Device.

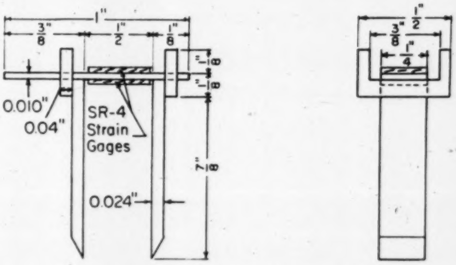

Fig. 6.—Clip Gage.

It was recognized that the electrical resistance and hence the gage factor of the electric strain gages would change with temperature. The change in resistance was nullified by using compensating gages at the same temperatures at which the strain-measuring gage was used. The change in the gage factor was considered to be less than 1 per cent for the range of temperatures encountered. This conclusion was based on the results reported by Day and Sevand (**12**). In view of the small temperature effect reported, the change in the gage factor was neglected.

Tension Test Equipment:

A specially constructed machine was used to test the magnesium alloy specimens in simple tension at low temperatures. As shown in Fig. 7, the machine consisted of a frame with a hydraulic push-pull jack, *J*, attached to the top, specimen grips, *G*, and a specially constructed dynamometer, *D*. The dynamometer consisted of a piece of steel with two SR-4 electric strain gages glued to it. The dynamometer was calibrated in a universal testing machine so that readings of strain could be converted to load. The strains in the tension specimens were measured using SR-4 strain gages for the elastic range and a clip gage, for the plastic range. The clip gage was very similar to those used on the bulge specimens, as shown in Fig. 6, except that the gage length was $\frac{1}{4}$ in. instead of $\frac{1}{2}$ in.

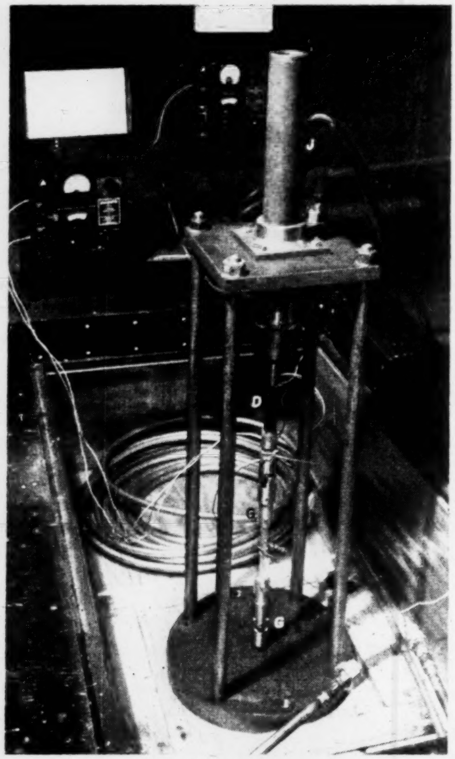

FIG. 7.—Simple Tension Machine.

Low-Temperature Equipment:

All the tests at low temperatures were performed inside a deep freeze unit, as

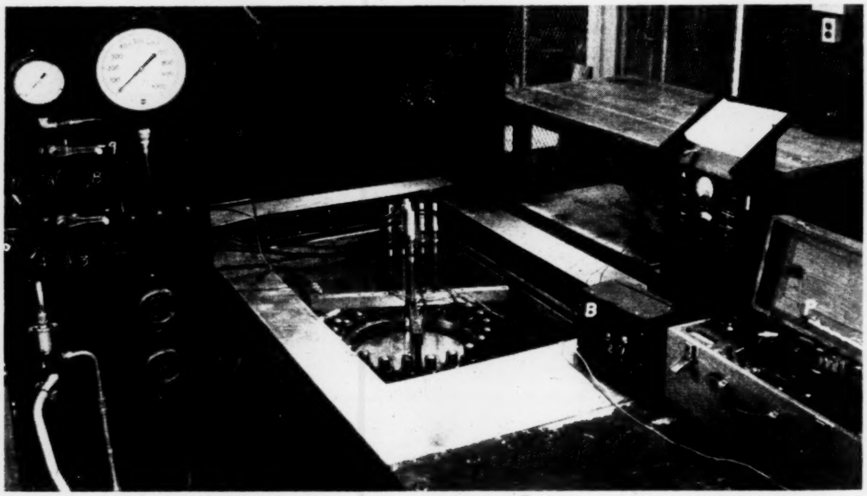

FIG. 8.—Bulge Test Apparatus.

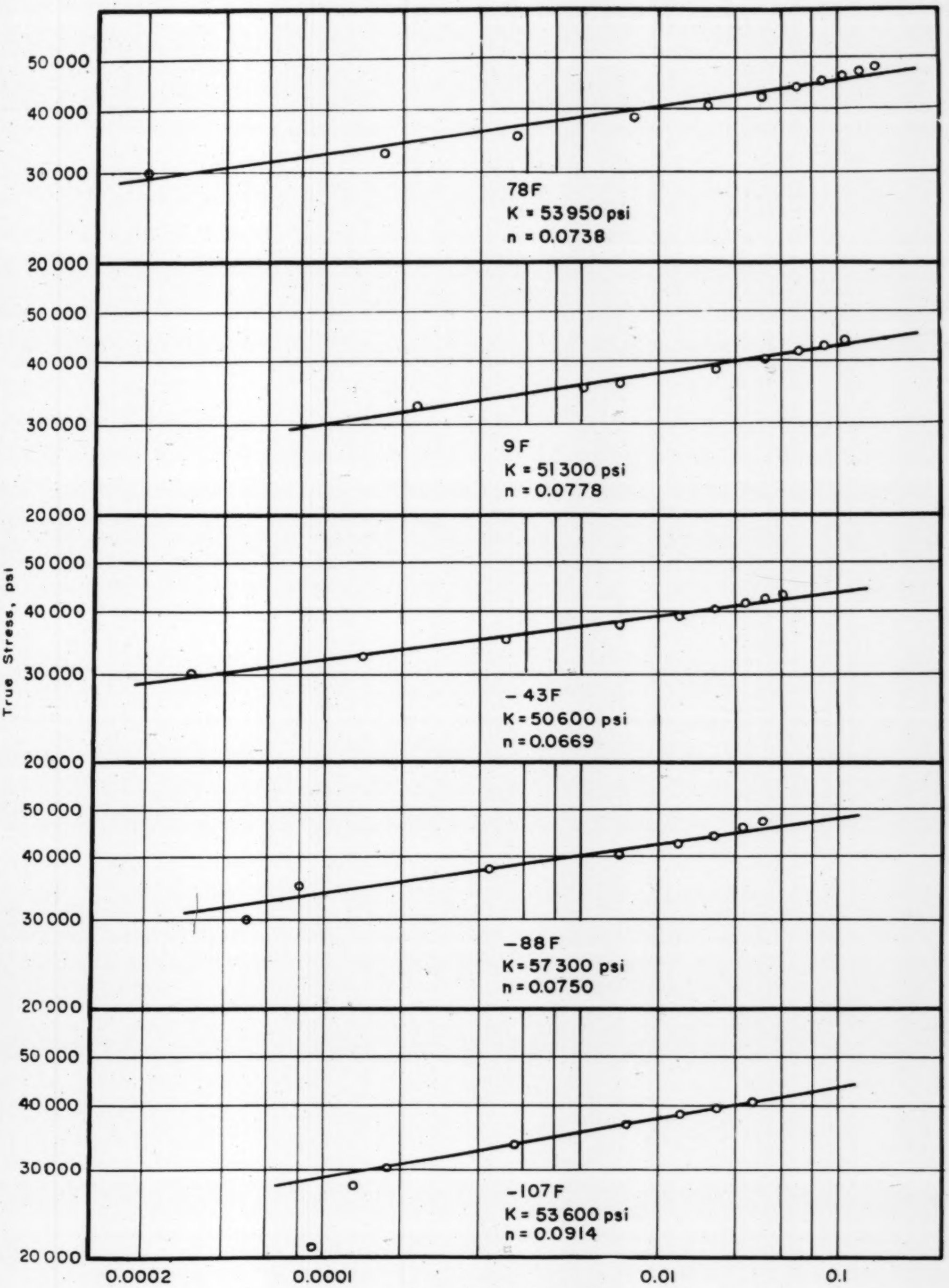

FIG. 9.—True Stress and True Strain Curves from Simple Tension Tests on Magnesium Alloy FSI-H24 at Various Temperatures.

shown in Fig. 8. The deep freeze was designed for use at temperatures as low as −150 F. The cold box was approximately 4 ft long, 2 ft wide, and 14 in. deep. A special lid was constructed with a hole near the center to allow space for the spark-recording apparatus and the tension-testing machine. The spaces around the spark recorder were closed with insulating board, and the spaces around the tension-testing machine were closed with cork. The deep freeze had a Foxboro temperature controller as part of its standard equipment. Since the controller registered the temperature of only one corner of the cold box, a thermocouple, *T*, was used in conjunction with a portable potentiometer, *P*, to give the exact temperature of the specimens (Figs. 2 and 8).

Test Procedure:

Figure 8 shows a view of the entire assembly ready for testing. Before a specimen was placed in the bulge tester, its thickness was measured with a dial gage supported on the measuring microscope (Fig. 5). SR-4 gages and hooks for mounting clip gages were then glued on the specimen. After the glue had dried, the specimen was bolted in the bulge tester, and the tester was lowered into the deep freeze. A splash shield, the spark recorder supporting frame, and the clip gages were all fastened in place before the insulated lid was lowered on the deep freeze unit. The strain gages were then connected to an SR-4 strain gage indicator, *I*, through a switch box, *B*. The spark recorder was assembled, and the pressure generating system was connected to the bulge tester (Fig. 8). The deep freeze unit was then started and left for a period of about 16 hr before the specimen reached the desired test temperature.

During the actual test run, the strains and the deflections of the bulge at various points were recorded for various values of pressure. The temperature was also noted before, during, and after the test. After the specimen broke the spark, records were measured with the measuring microscope to give the deflection of the bulge at the various stations.

The tension tests were simpler to run than the bulge tests, since the tension-testing machine did not have to be removed from the deep freeze to change specimens. The testing machine was cooled before the specimen was inserted and before the clip gage was attached. For each test, readings of strain were recorded for various loads, and the temperature of the specimen was noted before and after the run.

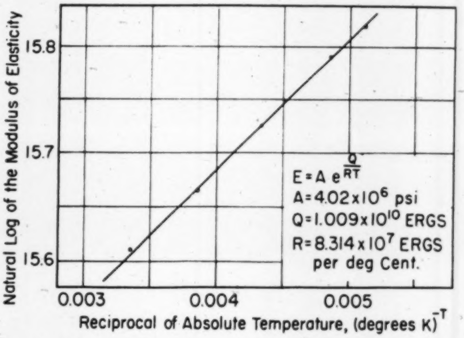

FIG. 10.—Natural Log of the Modulus of Elasticity *versus* Reciprocal of Absolute Temperature.

TEST RESULTS

Simple Tension Results:

The stress-strain results in simple tension for the various test temperatures are shown in Fig. 9. The stress-strain relations are for true stress and strain. The data in Fig. 9 are plotted on log-log coordinates in order to determine the validity of the empirical stress-strain relation:

$$\sigma = K\delta^n \qquad (1)$$

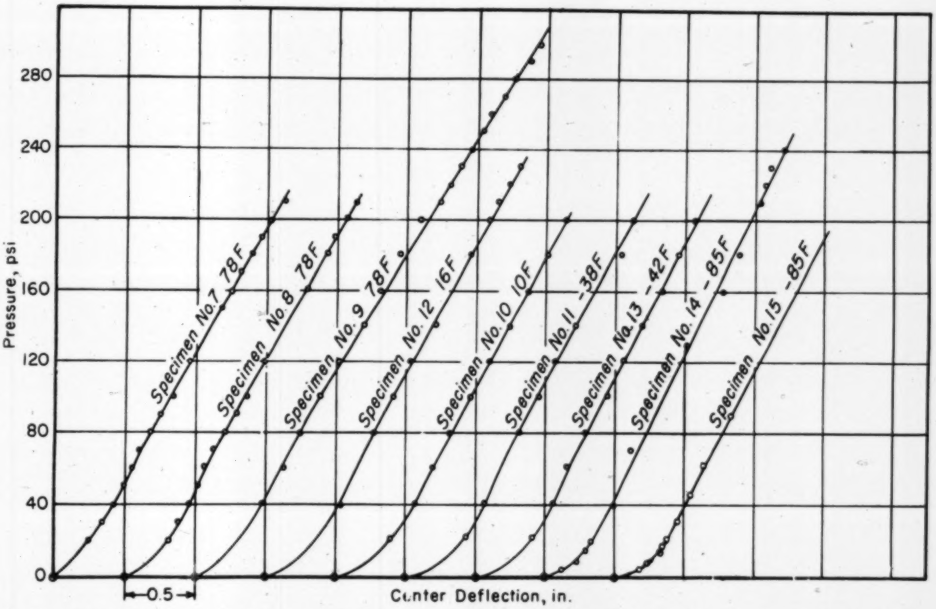

FIG. 11.—Pressure and Center Deflection Curves for Circular Bulge Specimens on Magnesium Alloy FSI-H24 at Various Temperatures.

where:

n = the strain hardening exponent,
K = the strength coefficient,
σ = the true stress, and
δ = the true strain.

An examination of Fig. 9 shows that the test results can be approximately represented by the straight-line relations expressed by Eq 1. Values of the constants K and n, expressed in Eq 1, are given in Fig. 9 for each test temperature. No systematic variation was found to exist between the constants K and n and the temperature. The variation in the modulus of elasticity with temperature is shown in Fig. 10. A semi-log plot of the reciprocal of the absolute temperature, T, *versus* the modulus of elasticity, E, is given in Fig. 10, showing good agreement between test points and the straight line shown. That is, the empirical relationship between the modulus of elasticity and the absolute temperature can

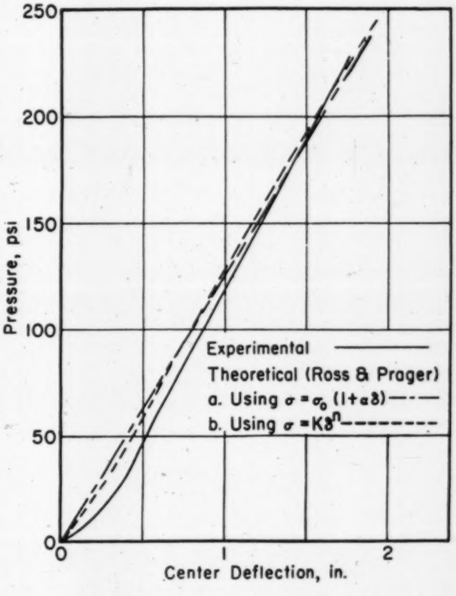

FIG. 12.—Comparison of Experimental and Theoretical Pressure and Center Deflection Curves.

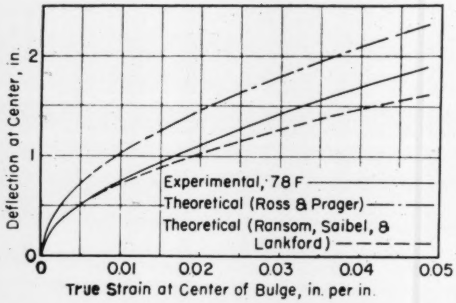

FIG. 13.—Comparison of Experimental and Theoretical Deflection—Strain Relations for Center of Circular Bulge Specimens.

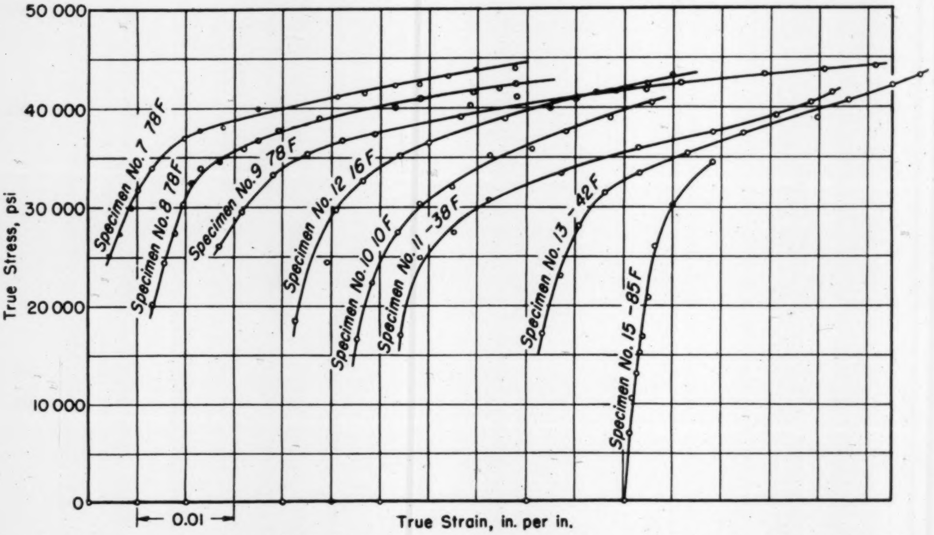

FIG. 14.—True Stress and True Strain Curves for Center of Circular Bulges on Magnesium Alloy FSI-H24 at Various Temperatures.

be defined by:

$$E = Ae^{Q/RT} \qquad (2)$$

where e = base of natural logarithms, and A, Q, and R are material constants. Values of the material constants A, Q, and R are given in Fig. 10.

Bulge Test Results:

Figure 11 shows the relation between the applied pressure and the center deflections for each of the nine bulge specimens tested. It can be seen from Fig. 11 that temperature has no detectable effect on the pressure-deflection relation. Figure 12 shows the actual pressure-center deflection curve for the bulge specimen tested at room temperature. Theoretical pressure-center deflection relations, as determined by the method of Ross and Prager (**13**), are also shown in Fig. 12. One of these theoretical relations is based on the simple tension relation, $\sigma = \sigma_0 (1 + \alpha\delta)$, while the other is based upon the simple tension relation, $\sigma = K\delta^n$. It is seen from Fig. 12 that the two theoretical curves agree with each other quite well and that, particularly for the higher pressures, the theoretical relations agree fairly well with the experimental results.

Several theoretical methods relating the strain in a circular bulge with the center deflection have been derived. Two of these methods, one by Saibel, Ransom, and Lankford (**14**) and the other by Ross

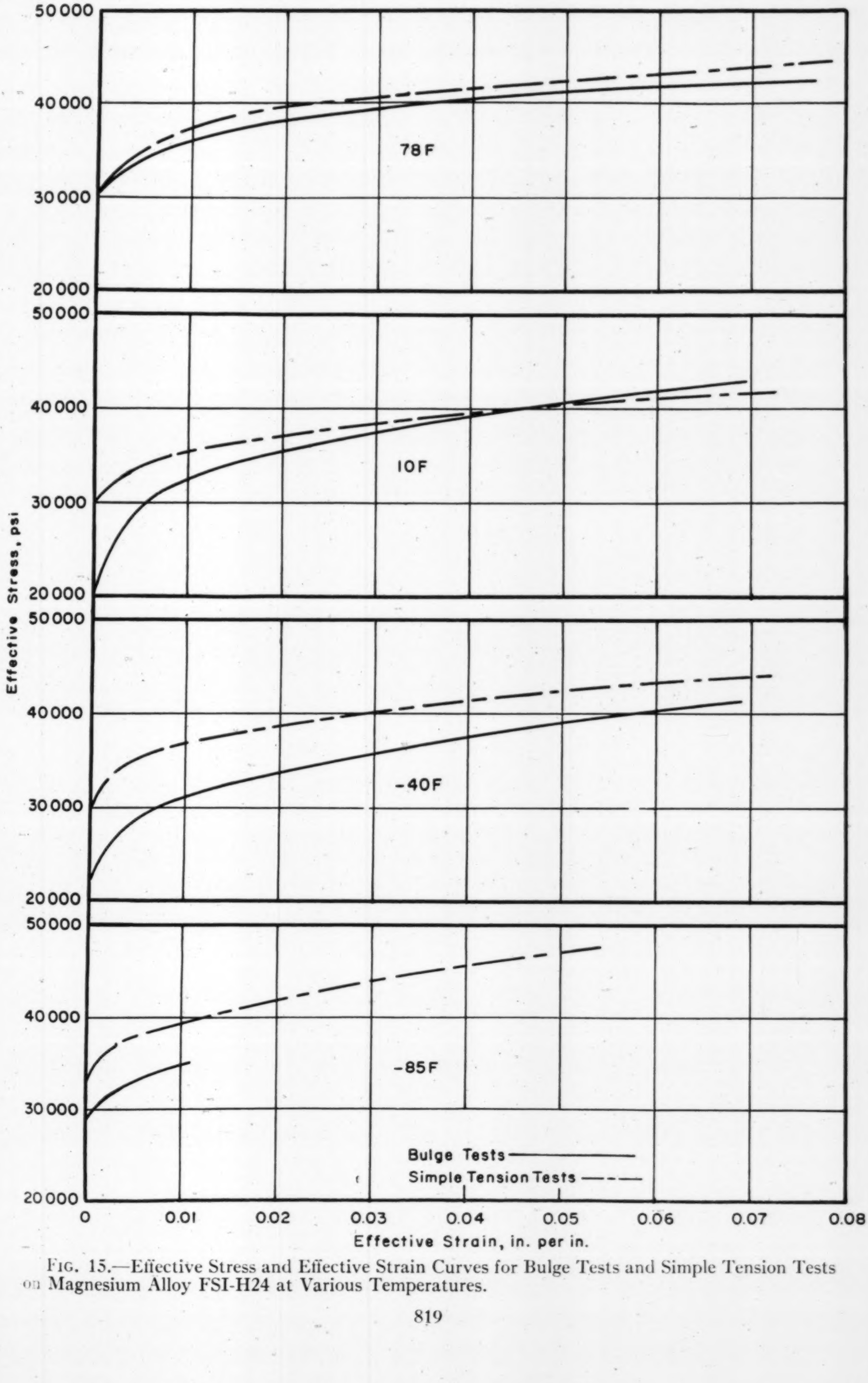

FIG. 15.—Effective Stress and Effective Strain Curves for Bulge Tests and Simple Tension Tests on Magnesium Alloy FSI-H24 at Various Temperatures.

and Prager (13), are compared in Fig. 13 with the room-temperature bulge test results. It is seen that the experimental curve falls between the two theoretical curves and that neither curve agrees with the experimental data very closely.

Figure 14 shows the true stress-strain relations for the material at the center of the bulge. The true stresses plotted in Fig. 14 were calculated from the center deflection of the bulge, the applied pressure, the radius of the clamping ring, and the thickness of the specimen (1). The strains in Fig. 14 are averages of the strains measured at and near the center of the bulge in both the rolling and transverse directions. An average of these strains was taken because the experimental technique was not accurate enough to detect any consistent variation of strain with change in the direction of the strain measurement. As in the case of the simple tension tests, no systematic variation of the stress-strain relation with temperature could be determined.

INTERPRETATION OF TEST RESULTS

Stress-Strain Relations:

To determine whether the plastic stress-strain relations for combined stresses can be predicted based on the simple tension test results, the simple flow-type theory has usually been used (15). The simple flow theory requires that the effective stress-strain curves for biaxial tension coincide with the true stress-strain curves for simple tension. For biaxial stresses, σ_1 and σ_2, the effective stress can be shown to be (15):

$$\bar{\sigma} = \sqrt{\sigma_1^2 - \sigma_1\sigma_2 + \sigma_2^2} \quad \ldots\ldots (3)$$

The effective strain for the tests under consideration can also be shown to be (15):

$$\bar{\delta} = \sqrt{\tfrac{2}{3}(\delta_1^2 + \delta_2^2 + \delta_3^2)} \quad \ldots\ldots (4)$$

where δ_1, δ_2, δ_3 are the plastic strains in the principal stress directions.

Figure 15 gives the effective stress-strain curves for both the bulge specimens and the simple tension specimens at the four different test temperatures used. It is seen from Fig. 15 that the best agreement between the theoretical and experimental results occurs at room temperature and that the agreement becomes poorer as the temperature decreases. In all cases, the effective stress-strain curves for the bulge specimens lie below the corresponding curves for simple tension, with the exception of the tests at 10 F where the effective stress-strain curves cross.

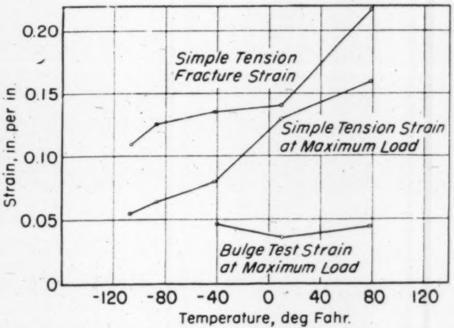

FIG. 16.—Variation of Ductility with Temperature for Magnesium Alloy FSI-H24.

Ductility:

Figure 16 shows the variation with temperature of (*a*) the average fracture strains in simple tension, (*b*) the strains at maximum load in simple tension, and (*c*) the center principal strains at maximum load in the bulge tests. For simple tension, both the fracture strain and the strain at maximum load decrease as the temperature decreases. The center principal strain at maximum load in the bulge tests does not appear to be affected by temperature, although more data is needed before a definite statement can be made on this point. Contrary to the results obtained by other investigators (7), the strains in the bulge specimens at maximum load were considerably smaller than the corresponding strains in simple tension.

Types of Fracture:

At room temperature, the tension specimens failed with a ductile type fracture accompanied by some local necking. At lower temperatures, the local necking became less pronounced. The bulge test specimens fractured with little local reduction in the thickness for all test temperatures. The fractures in these latter tests were irregular and sometimes consisted of two or more fractures leading in various directions from the center of the specimens.

CONCLUSIONS

For the magnesium alloy FS1-H24 tested, the following conclusions have been drawn:

1. The plastic true stress-strain relations for simple tension could be expressed only approximately by the commonly used empirical equation $\sigma = K\delta^n$.
2. The relation between modulus of elasticity in simple tension E and the absolute temperature T was found to be expressed approximately by, $E = Ae^{Q/RT}$.
3. The combined plastic stress-strain relations, as determined by the bulge tests for various temperatures, were found to be in good agreement with values predicted by the simple flow-type theory.
4. The ductility was found to be smaller under biaxial tension than under simple tension.
5. For the range of temperatures considered, the ductility in simple tension decreased with decrease in temperature. However, the ductility under balanced biaxial tension was not affected by changes in temperature.

Acknowledgment:

The research described in this paper was conducted in the Plasticity Laboratory of the Department of Engineering Mechanics at The Pennsylvania State University. The study was conducted under the sponsorship and financial support of the Office of Ordnance Research. The Dow Chemical Co. donated sheets of magnesium alloy used for the test specimens. H. A. B. Wiseman and Homer Johnson assisted in this research program. The authors express their appreciation to the foregoing organizations and individuals for making possible this study.

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DISCUSSION

Mr. A. H. Kidder.[1]—The test described is intriguing—working in terms of spherical tension. One of the difficulties is getting the deflections accurately. I wonder if the authors had thought of testing cylinders with suitable plugs in the ends of them. That would give a biaxial strain a little easier to interpret.

Mr. Edward Paxson (*author*).—We have done a good bit of this work with cylinders at Pennsylvania State University. We did think about using this type of test when we considered a low-temperature program. The primary reason we went in for the bulge test program was that we wanted to try to develop large strains.

I admit the instrumentation is difficult, and we certainly have not solved it completely. I think your point is a good one.

Mr. Joseph Marin (*author*).—I might add to that, that tubular specimens are much more complicated to make, whereas with a sheet, you can use the sheet as is with holes drilled around the edge.

Mr. Carl E. Hartbower.[2]—Referring to Fig. 16, ductility in simple tension is clearly temperature-dependent for the magnesium alloy investigated. Over the range of temperature investigated, ductility in balanced biaxial tension does not appear to be affected by temperature. However, might not the bulge-test curve have swept upward to higher ductility values had higher temperatures been investigated? It should be emphasized that conclusion (No. 5) ". . . the ductility under balanced biaxial tension was not affected by changes in temperature" holds only for the range of temperatures investigated.

Mr. Paxson.—I think that is probably quite likely. We were not equipped to run any of the temperature tests higher than room temperature.

Mr. Hartbower.— The initial bulge is circular, but as the deformation is increased a secondary bulge is developed on top of the initial bulge. Was such a point of plastic instability reached? What type of fractures developed?

Mr. Paxson.—The fractures which we obtained were definitely of a brittle nature. They were jagged and not clean cut with fractures often at two or three locations. The fracture was not always through the center of the specimen. We did not notice any secondary bulge effects.

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[1] Engineer in Charge of Testing Div., Philadelphia Electric Co., Philadelphia, Pa.

[2] Chief, Metals Fabrication Branch, Watertown Arsenal Laboratories, Watertown, Mass.

CERTAIN DEPARTURES FROM PLASTIC IDEALITY AT LARGE STRAINS*

By H. A. Lequear[1] and J. D. Lubahn[1]

Synopsis

Previous conclusions, which were restricted to plastic strains of less than 1 per cent (**1**),[2] have been extended by additional experiments to cover strains up to necking (30 per cent). The experiments, consisting of room temperature tests on OFHC copper, show that the results of creep tests and tension tests can be related, within certain limitations, in terms of the rate sensitivity. Rate sensitivity is the increase in stress required to cause a certain increase in strain rate at a given strain. The above relation between creep and tension behaviors is a consequence of the concept that plastic deformation behavior depends essentially on current conditions and not on the prior history. This relation is restricted to isothermal conditions and monotonic loading (increasing or constant, but not decreasing, load).

For many years the materials testing engineer has been intrigued by the possibility that creep tests and tension tests can be related to each other. Such a relationship might be based on any one of several concepts which have been put forward in recent years. One concept which has received considerable attention is called the "strain hardening theory of creep," "plastic ideality" (**1**),[2] or "the mechanical equation of state" (**2, 3, 4**). According to this concept, the plastic deformation behavior depends only on the current conditions, and not on the past history of the deformation.

It is now well established that the temperature of prior deformation affects the current behavior, but the possibility still remains that the rate of prior straining does not affect the current behavior, particularly at lower temperatures where metallurgical changes are absent (**4**). If this is true, isothermal creep and tension tests could be related by a simple cross-plotting procedure (**4**). To obtain a tension curve from a family of creep curves at various stresses, the stress and strain could be picked from the creep curves at a given strain rate for which the tension curve is to be constructed, and these stress and strain values could be plotted against each other to obtain the desired tension curve. In a similar manner, to obtain a creep curve from a family of tension curves at various strain rates, the strains and rates could be picked from the tension curves at the desired stress, and these strain and rate values plotted

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* Presented at the Fifty-eighth Annual Meeting of the Society, June 26–July 1, 1955.

[1] Metallurgy Research Dept., General Electric Co., Schenectady, N. Y.

[2] The boldface numbers in parentheses refer to the list of references appended to this paper, see p. 843.

against each other to obtain a curve which is related to the desired creep curve by the relation (4):

$$t = \int dt = \int \frac{d\epsilon}{\left(\frac{d\epsilon}{dt}\right)} = \int_0^\epsilon \frac{d\epsilon}{\dot\epsilon}$$

where t is time, ϵ is plastic strain, and $\dot\epsilon$ is strain rate.

Those aspects of the concept of plastic ideality which permit the construction of a tension curve from creep data seemed fairly well substantiated from earlier work (5, 6), but the more difficult construction of creep curves from tension data at first (5) did not appear to be of accurate practicality for the small values of rate sensitivity associated with comparatively low temperatures. "Rate sensitivity," n', is a measure of how much more stress, S, is required to cause a desired increase in strain rate at a given strain. Quantitatively it is defined as the slope of a graph of log stress *versus* log rate at a given strain:

$$n' = (\partial \log S/\partial \log \dot\epsilon)_\epsilon$$

When n is very small, the tension curves for identical specimens tested at rates which cover as wide a range as practical would not be any more different than the normal scattering in deformation resistance. Under these conditions, if one attempted to cross-plot a family of tension curves at various rates, one would obtain only a buckshot pattern, from which a creep curve would not be forthcoming.

To circumvent the above difficulties due to small rate sensitivity, the concept of plastic ideality was applied (5) in a form somewhat different from the simple cross-plotting described previously, and employing the rate sensitivity, n', the strain hardening rate

$$m' = (\partial \log S/\partial \log \epsilon)_{\dot\epsilon}$$

and a quantity "p'" characterizing the shape of the creep curve

$$p' = (\partial \log \dot\epsilon/\partial \log \epsilon)_s$$

This latter quantity tells how fast the creep rate diminishes in a creep test. In terms of n', m', and p', the plastic ideality concept can be expressed by the relation

$$p' = -\frac{m'}{n'}.$$

Mathematically, this equation follows directly from the hypothesis that stress is a function of strain and rate only. Also, an earlier paper (5) gives a derivation on the basis of a physical picture.

Early attempts (5) to apply the equation $p' = -m'/n'$ met with only qualitative success because of scattering among the specimens used to measure the various derivatives p', m', and n', even though n' was measured on a single tensile specimen by suddenly changing the rate (transient test). A new technique (1), using a single specimen to measure all the derivatives, showed good results, at least at small plastic strains (up to about 1 per cent). To keep the calculations on the large mass of data to a minimum, the derivatives were expressed in terms of the experimental quantities of load, P, extension, δ, and extension rate, $\dot\delta$, rather than the derived quantities S, ϵ, and $\dot\epsilon$, thus:

$$p \equiv \left(\frac{\partial \log \dot\delta}{\partial \log \delta}\right)_P = -\frac{\left(\frac{\partial \log P}{\partial \log \delta}\right)_{\dot\delta}}{\left(\frac{\partial \log P}{\partial \log \dot\delta}\right)_\delta} \equiv -\frac{m}{n} \quad (1)$$

The present investigation extends the earlier work to cover the range of strains up to necking (about 30 per cent), and shows that the application of Eq 1 to tension and transient test data does permit the calculation of room-tempertaure creep curves of copper. The following

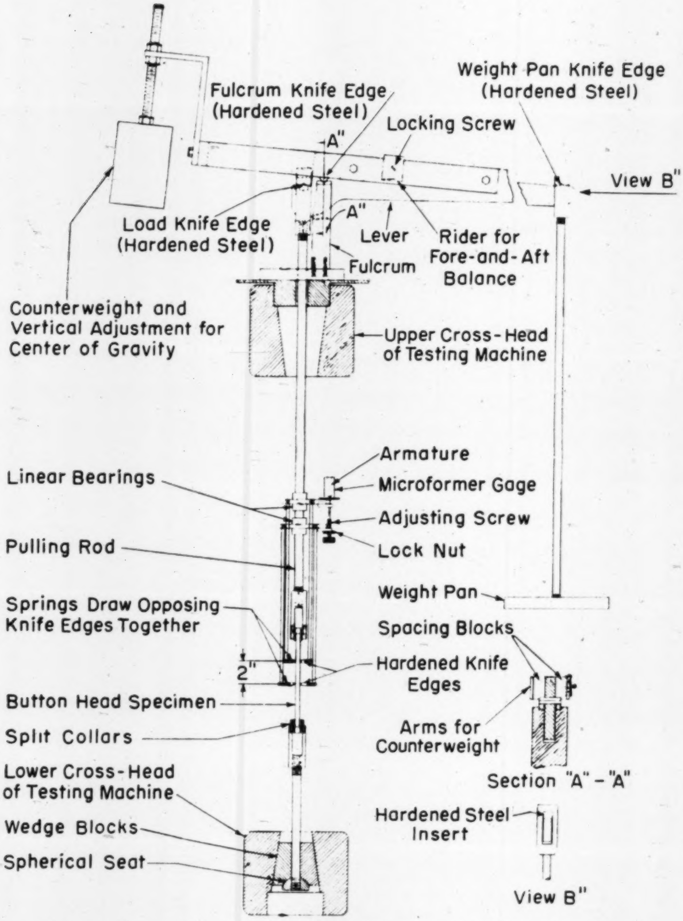
Fulcrum Knife Edge
(Hardened Steel)
Weight Pan Knife Edge
(Hardened Steel)
Locking Screw
A"
View B"
Load Knife Edge
(Hardened Steel)
A"
Lever
Rider for
Fore-and-Aft
Balance
Fulcrum
Counterweight and
Vertical Adjustment for
Center of Gravity
Upper Cross-Head
of Testing Machine
Armature
Microformer Gage
Linear Bearings
Adjusting Screw
Pulling Rod
Lock Nut
Weight Pan
Springs Draw Opposing
Knife Edges Together
Spacing Blocks
2"
Hardened Knife
Edges
Button Head Specimen
Split Collars
Arms for
Counterweight
Lower Cross-Head
of Testing Machine
Section "A" - "A"
Wedge Blocks
Hardened Steel
Insert
Spherical Seat
View B"

FIG. 1.—Experimental Setup for Tests up to the Necking Strain.

discussion will deal not only with the validity of Eq 1 for the particular conditions of this investigation but also will discuss the possible limitations on the applicability of Eq 1 to other temperatures or materials.

MATERIAL AND SPECIMENS

The material used was OFHC copper with a nongaseous impurity content of 0.004 per cent (exclusive of silver) determined by spectroscopic analysis. This copper was hot worked to $1\frac{1}{4}$ in. round and then cold drawn to $\frac{1}{2}$ in. round without intermediate anneals (84 per cent reduction of area). The specimens were 0.300 in. in diameter over an $8\frac{1}{4}$-in. cylindrical length between $\frac{1}{2}$-in. diameter, $\frac{3}{8}$-in. long button heads with 0.020-in. fillet radius under the heads. In attempting to turn such specimens from the cold-drawn material, considerable difficulty was experienced with warpage during machining. Consequently, lengths of rod were first annealed for 1 hr at 600 C and then carefully machined to the above shape without difficulty. However, it is entirely possible that some plastic strain was introduced during the machining.

EQUIPMENT

The tests were set up in an hydraulic tension testing machine (Fig. 1). The fulcrum for the lever was mounted on the upper crosshead of the machine in a manner that allowed a rod to extend from the lever freely through the crosshead to the specimen and thence to a fastening at the lower crosshead.

Extension was measured between spring-loaded knife-edges 2 in. apart on the cylindrical portion of the specimen. The relative motion between the two ends of the gage length was transferred by $\frac{1}{4}$-in. steel rods to two carriages running on linear bearings on the upper pulling rod. In preliminary tests, two different types of gages were used simultaneously to measure the relative motion of the carriages, but the results agreed[3] so closely (Fig. 2 is typical), except for occasional difficulties with long-time stability (7), that in subsequent tests only the microformer gage was used. The microformer was taken from a standard Peters P2M-1 extensometer and mounted vertically on the upper carriage. The armature rested on a pointed adjusting screw threaded through the lower carriage for the purpose of periodic resettings. The gage was used in conjunction with a Baldwin-Southwark recorder fitted with a synchronous-motor drive capable of four successive quick changes of pen speed of 30:1 each (8).

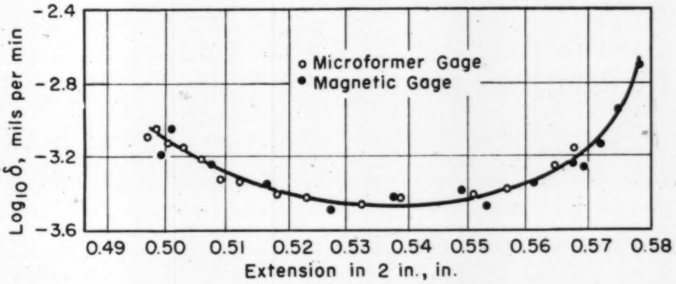

FIG. 2.—Creep Behavior at a Load That Approximates Maximum Load in a Tension Test.

On the highest magnification, the Peters gage causes 2-in. movement of the chart paper nominally for 0.001 strain on a 1.4-in. gage length with an 0.75:0.175 magnifying lever transmitting knife-edge motion to the microformer. Thus, the microformer alone would nominally produce 1 in. of chart movement for 0.003 in. of armature displacement. This nominal calibration was checked (7) by using the gage to measure extension of an elastic specimen. The average of two calibrations was within 2 per cent of the nominal calibration of 0.003 in. of armature displacement per inch of chart motion. The microformer gage was always used on the most sensitive range and had to be reset about every 5 per cent strain. The gage was never reset during a test, but it was set ahead artificially (5) to avoid missing the early part of the creep curve when the initial creep rate was too large for the recorder to follow.

The lever was the same as that used previously (1). It was carefully adjusted so that the center of gravity was at the fulcrum and the lever ratio of 17.6:1 did not change with angular position by more than 0.05 per cent (9).

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[3] In order to plot the results from both gages on the same extension scale, extension increments were plotted beginning at a common point at the start of the test where the pens for both recorders were set down on the paper simultaneously.

TEST PROCEDURE AND ANALYSIS OF RESULTS

In order to avoid earlier difficulties (5) arising from differences among different specimens, all the derivatives in Eq 1 were measured on the same specimen. This measurement was made by alternating creep tests, from which p is determined, and transient tests, from which n is determined, and plotting both p and n as a function of extension. Since p, m, and n all are determinable as functions of strain, each can be plotted *versus* strain and a set of values of the three derivatives can be picked from these curves at any desired strain, for purposes of examining the validity of Eq 1.

The results were finally expressed as $-\frac{pn}{m}$ *versus* strain, departures from unity indicating deviations from plastic ideality (see Eq 1). Strictly speaking, Eq 1 is valid only for stated values of both strain and strain rate, so that p, m, and n should all be measured at the same strain rate, as well as at the same strain. It will be shown, however, that neither m, p, nor n varies significantly with strain rate in the range covered by a single test, and consequently all three derivatives may be considered as having been measured at the "standard rate" (namely the rate at which the load-extension curve was measured).

At the beginning of each test, the load was applied in small steps, each load being maintained for a time to ascertain whether creep was occurring. This process was continued until the amount of creep strain at constant load was large enough to be able to determine how the creep rate varies with strain. At the end of any given constant load period, the load was increased sufficiently to bring the creep rate to a high value again, so that in the subsequent constant load test there would be as wide a range of rates as possible.

In making a creep test, the weight was added to the weight pan manually in 1 or 2 sec. This procedure was found to be almost as rapid and just as accurate as hydraulic-jack loading, and considerably simpler (1).

Although the creep and transient tests described above are all that are needed to measure the derivatives in Eq 1, one more type of test was performed in order to ascertain the presence or absence of effects due to metallurgical changes. This test consisted of interrupting a creep test by a period of time at zero load. The no-load period varied from as little as a few seconds to as much as several days. If the creep behavior following the no-load period were different from that in the no-load period by an amount dependent on the duration of the no-load period, one would conclude that the specimen was metallurgically unstable (10).

TEST RESULTS

At large strains the creep and transient effects are of the same general nature as those observed at small strains, but they sometimes differ markedly in degree.

Figure 3 is a typical chart record obtained with the microformer gage showing an interrupted creep test, a regular creep test, and a transient test with a load increment. From such chart records, log extension rate *versus* extension curves were plotted for both creep and transient tests in the same way as was done for the tests to small strains (1).

Figure 4 shows some creep test results that are typical of 18 creep tests at large strains. For strains less than about 20 per cent, the log $\dot{\delta}$ *versus* δ graphs are straight or nearly straight lines, as was

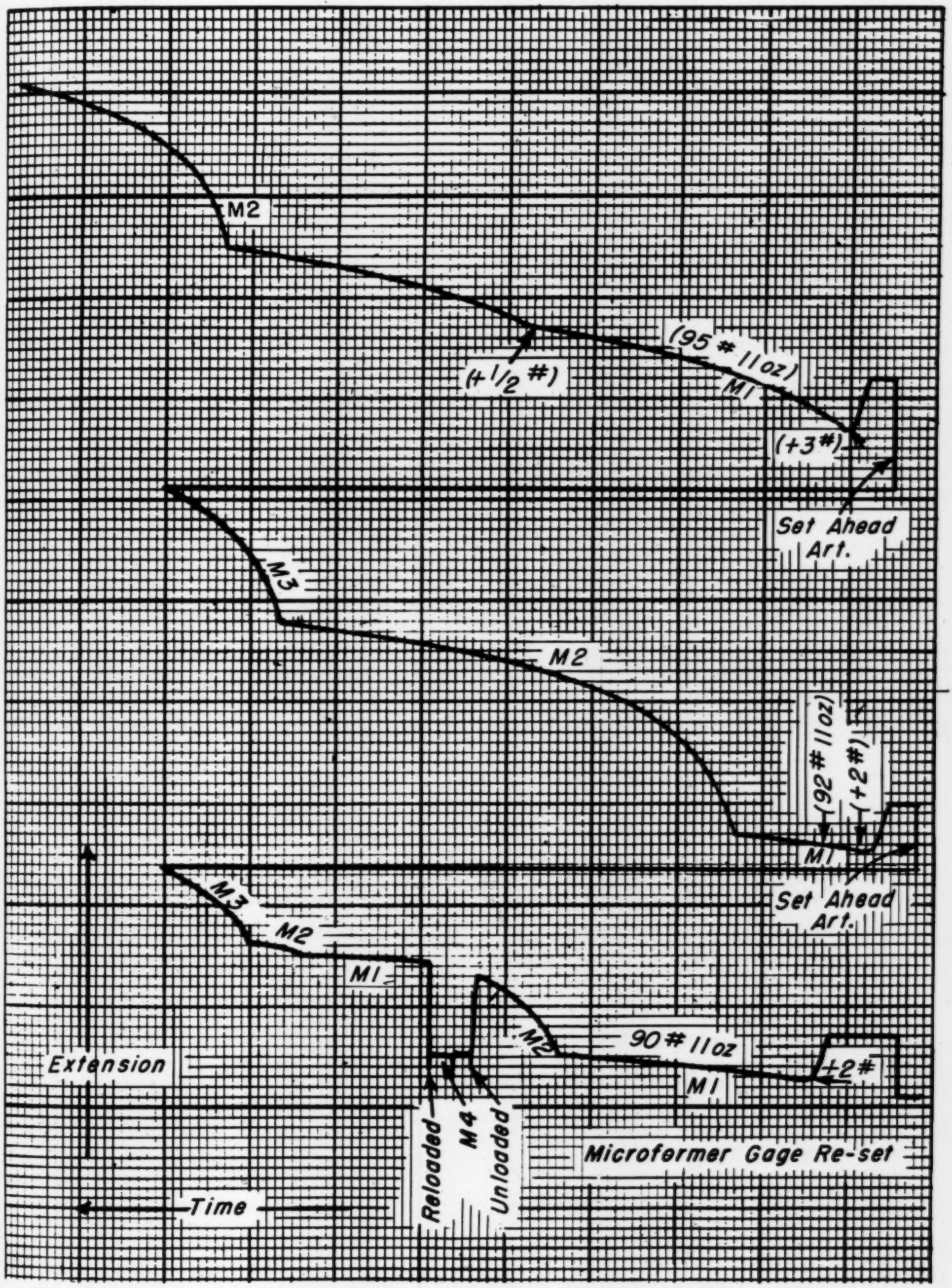

FIG. 3.—Microformer Recorder Chart Showing Interrupted Creep Test (Bottom), Uninterrupted Creep Test (Middle), and Transient Test (Top). Loads are at weight pan. 33 Small Squares = 10 mils extension. Pen Speed: M1 = 100, M2 = 3.18, M3 = 0.0978, M4 = 0.00308 Small Squares per minute.

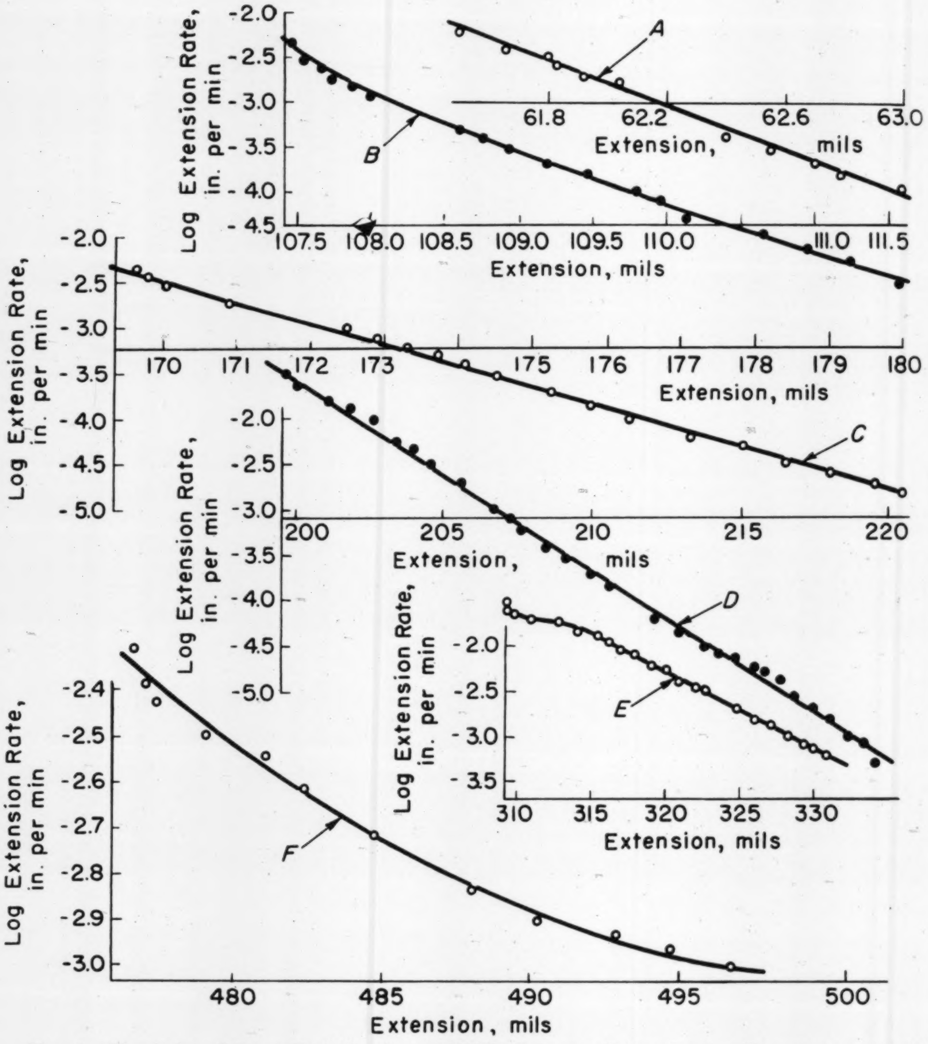

FIG. 4.—Examples of Creep Test Results on OFHC Copper at Large Strains. Room temperature. 2-in. gage length. For strains less than 20 per cent, curves *A*, *C*, and *D* are typical of 11 tests, *B* of two tests, and *E* of two tests. Curve *F* is typical of all three tests at strains above 20 per cent.

the case for the test results at smaller strains obtained with the magnetic gages (1). Of 15 tests at strains less than 20 per cent, 11 showed very straight log $\dot{\delta}$ - δ curves (curves *A*, *C*, and *D*), two had a slight disturbance at the beginning (curve *E*),[4] and two were slightly concave upward, though by an amount hardly greater than the scattering (curve *B*). Curve *A* shows typical scattering, while curves *D* and *C* show the largest and smallest scattering, respectively.

At strains larger than 20 per cent, there is a greater and greater tendency for the slope of the curve to become less negative as the test proceeds (see curve *F* in Fig. 4), and finally the slope passes

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[4] The effect is in such a direction that it might be explained as being due to a slight temporary overloading at the beginning of the test.

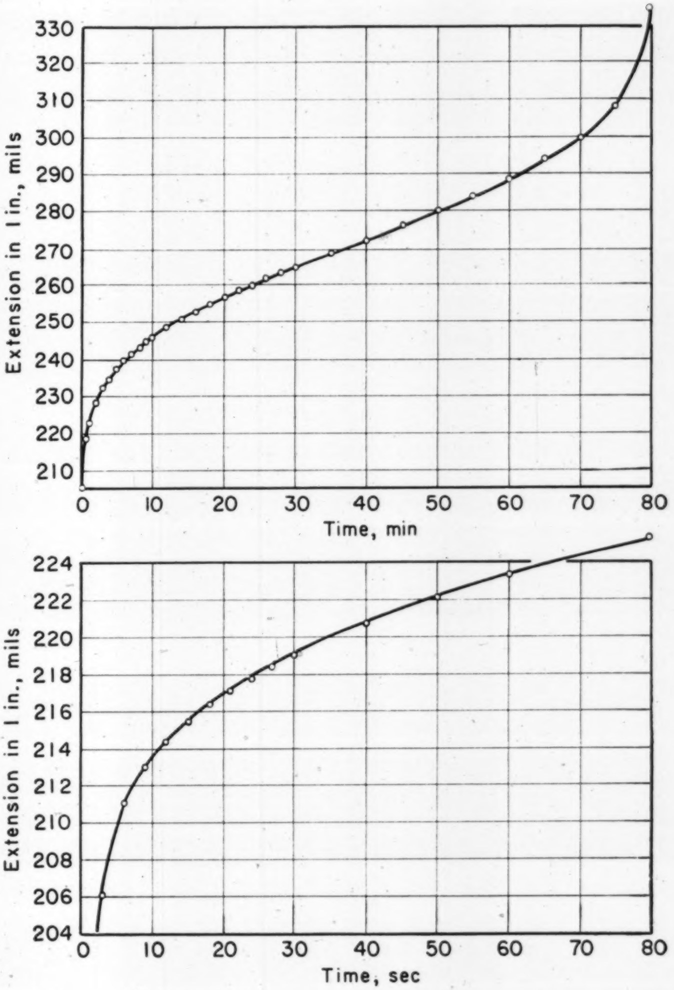

FIG. 5.—Creep Test on OFHC Copper (Annealed at 600 C) at Room Temperature and 676 lb (Initial Diameter = 0.1603 in.).

through zero and becomes positive at a strain approximately equal to the maximum load strain in a tension test (Fig. 2). The behavior shown in Fig. 2, where there was an inflection point in the creep curve with subsequently increasing creep rate, is more clearly shown in Fig. 5, where the entire test was made at a single constant load. In the test of Fig. 5, a pronounced neck, similar to that in a tension test, was seen developing shortly after the minimum in rate.

For the purpose of computing $p = \left(\frac{\partial \log \dot{\delta}}{\partial \log \delta}\right)_P = 2.303\,\delta\left(\frac{\partial \log_{10} \dot{\delta}}{\partial \delta}\right)_P$, the slope $(\partial \log_p \dot{\delta}/\partial\delta)_P$ of each creep curve was measured at its midpoint. Figure 6 shows how p varies with strain for strains up to the necking strain. The extreme left-hand portion of the trend curve has been drawn to conform to the trend curve for the tests at small strains (1). This trend curve does not disagree with the points corresponding to the smallest strains in Fig. 6, even though the two specimens had different grain sizes; but there is not the overlapping between the two sets of data to say whether or not they are mutually consistent. All that can be said is that p increases with strain at small strains and is at or about to pass through a maximum for the largest strain of this series of tests, and that p decreases with strain at larger strains. The last point, plotted at $p = 0$, represents the inflection point in the strain-time curve obtained when necking commenced. The two pairs of points marked *A* and *B* in Fig. 6 are from the second to the last and third to the last tests, where there was marked curvature of the log $\dot{\delta}$ - δ curve (see curve *F* of Fig. 4), and the two points of one pair correspond to slopes near the beginning and end of the curve. Although the scattering about the trend line at strains near 30 per cent is large compared with the magnitude of p, it is evident from points *A* and *B* that the variation with strain of the slope of the log $\dot{\delta}$ *versus* δ curve during a single test is similar to the variation from one test to another over a considerably larger range of strain.

According to Andrade (11), a constant-stress test (S = stress) should not result in an inflection point due to necking, as was the case for the constant-load test of Fig. 5. In other words, the creep rate would never pass through a minimum, and a graph of $(\partial \log \dot{\delta}/\partial \log \delta)_P$ for successive tests would not fall to zero. This behavior also means that $(\partial \log \dot{\delta}/\partial \log \delta)_S$ in a single test would not diminish so rapidly with strain as $(\partial \log \dot{\delta}/\partial \log \delta)_P$; and if it did not diminish with strain at all, the log $\dot{\delta}$ - log δ curve at the larger strains would be straight rather than curved, as were those at smaller strains. In order to verify these predictions, the value of $(\partial \log \dot{\delta}/\partial \log \delta)_S$ was calculated for each test. It was found (7) that these values do not diminish to zero, as was expected; but at large strains the slope of the log $\dot{\delta}$ - log δ curve for a single test still diminishes somewhat, although not so rapidly as in the measured curves for constant load tests. (The log $\dot{\delta}$ - log δ curves for constant stress can be calculated (7) from the rate sensitivity (Fig. 10), the strain, and the constant volume condition.)

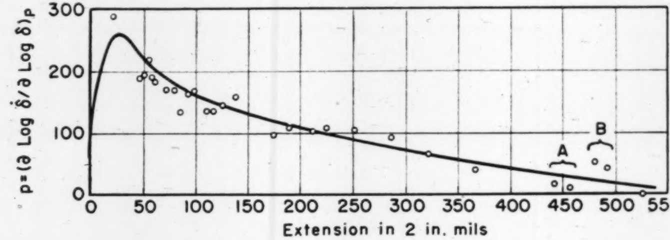

FIG. 6.—Variation of p with Successive Creep Tests. p is the slope of the log $\dot{\delta}$ - log δ curve measured at constant load.

The rate sensitivity at large strains was measured alternately with the creep behavior by transient tests in the same way as at small strains (1). Figure 7 shows some typical transient test results at large strains expressed as log extension rate *versus* extension. Of nineteen tests, five had one load increment (curve No. 8 in Fig. 7), seven had two load increments (curves Nos. 10 and 22), two had load changes similar to those in curve No. 30, three were like curve No. 36, and two had larger numbers of load changes. As in

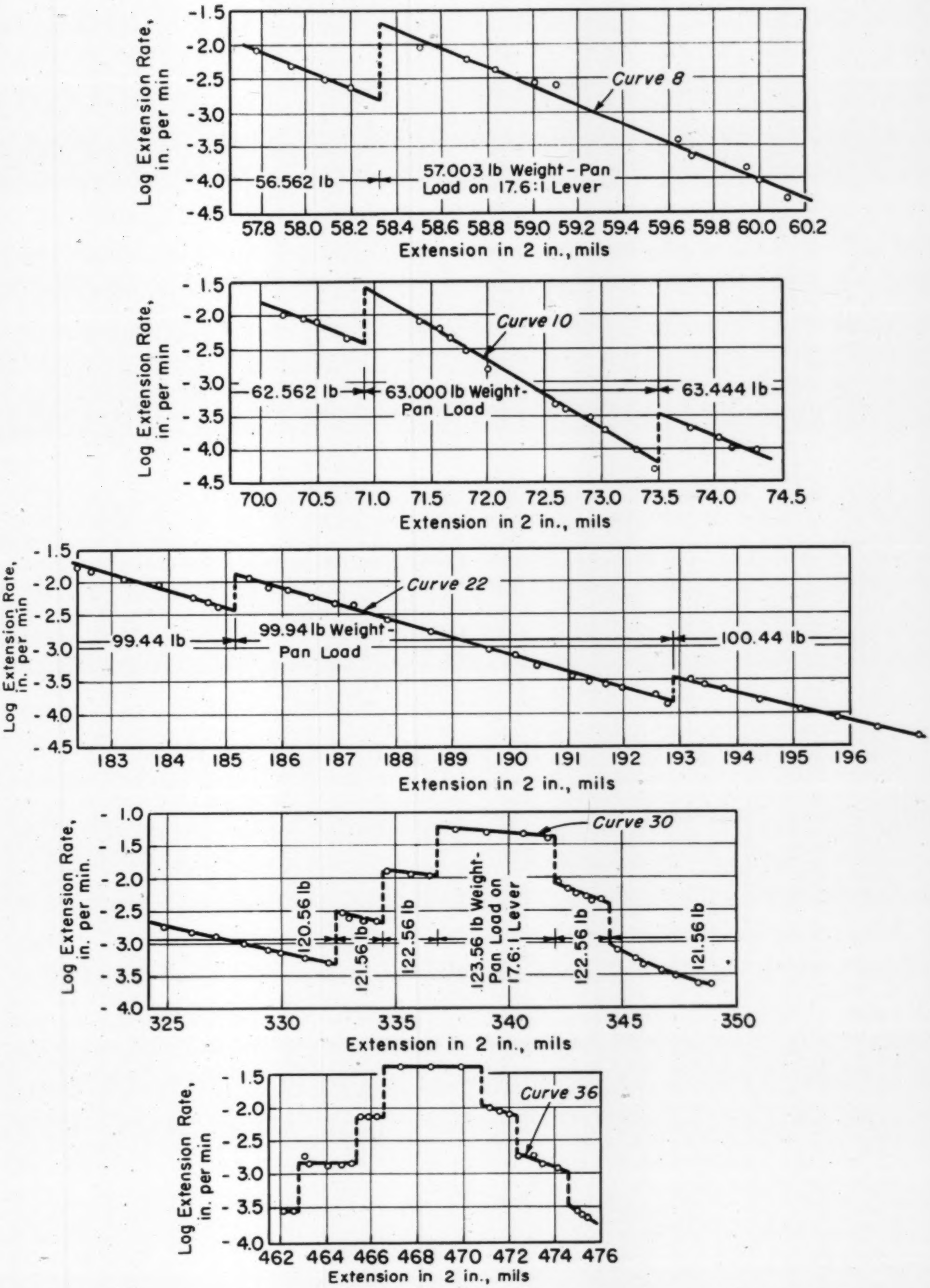

FIG. 7.—Examples of Transient Experiments. Initial specimen diameter: 0.300 in.

the tests at small strains (1), the curve segments for one test were roughly straight and parallel and offset approximately the same amount on a log rate scale for the same load change. The small departures from this general behavior that have been noted earlier for small strains were again evident, however. Curve No. 30 in Fig. 7 illustrates the small tendency for the slope to diminish with successive load increment, but it is the only good example of this effect. In the other tests, either the effect is absent or it is masked by the scattering in slope, which is a particularly high percentage near the necking strain, where the slope is small. Curves Nos. 10 and 22 in Fig. 7 show the maximum and minimum in scattering of slopes among successive curve segments. Curve No. 36 illustrates the tendency for the slope to be more negative after a load decrement than after a load increment. Figure 8, where load increments and decrements were alternated, furnishes a particularly striking example of the latter behavior.

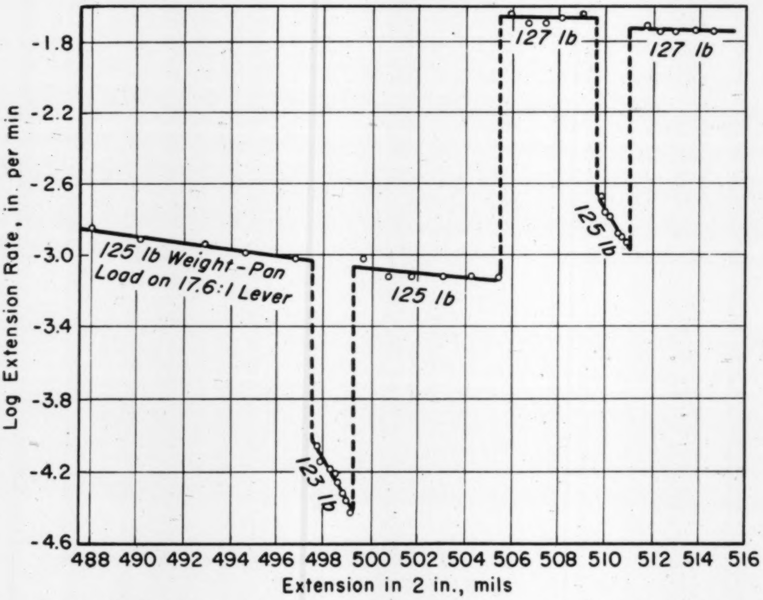

FIG. 8.—Transient Experiment on OFHC Copper in Which a Small Load Was Alternately Added and Removed. Initial diameter: 0.300 in.

The situation with regard to the slopes of successive curve segments in transient tests is summarized in Fig. 9. Figure 9 shows that the short curve segments following load increments in transient tests have slopes that define the same trend curve (except at the smallest strains where the trend curve is defined by only one point) as the slopes of the longer log $\dot{\delta}$ - δ curves obtained in the creep tests. Of course, the scattering in slope is larger for the shorter curve segments, because of the greater errors of slope measurement for a short curve segment. On the other hand, curve segments following small load decrements were considerably steeper than those following load increments, as shown by the filled triangles in Fig. 9. In other words, the creep rate diminished more abruptly after a load decrement than after a load increment. This behavior was apparently temporary, however, because a test that was continued to a much larger strain increment than the others (7) showed that the rate of diminution of the creep rate did not continue indefinitely at the abnormally high value prevailing immediately after the load decrement. The value of $(\partial \log \delta/\partial \delta)$ eventually reached in this test is shown as the filled circle in Fig. 9, which has a position near the trend line that characterizes the behavior following a load increment. The last portion of curve No. 30 of Fig. 7 also shows a tendency for the initially high slope following a load decrement to diminish gradually if given sufficient time.

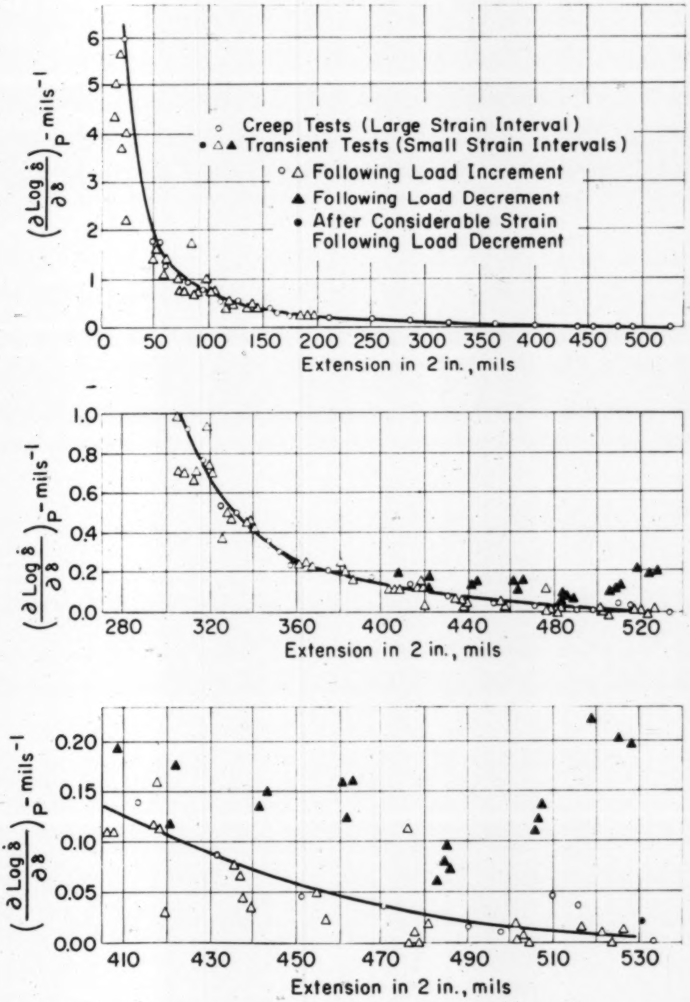

FIG. 9.—Effect of Strain Level on the Slope of the Log Extension Rate *versus* Extension Curve. Lower curves are magnifications of upper curve.

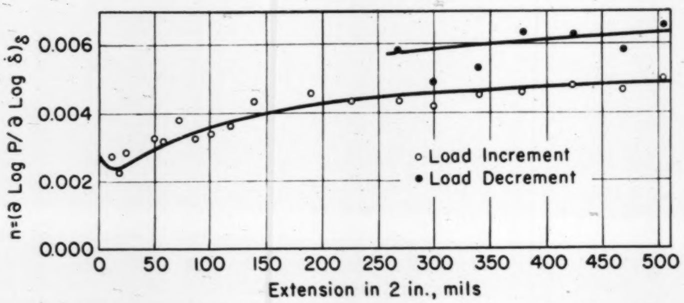

FIG. 10.—Variation with Strain of Rate Sensitivity, *n*, from Transient Tests.

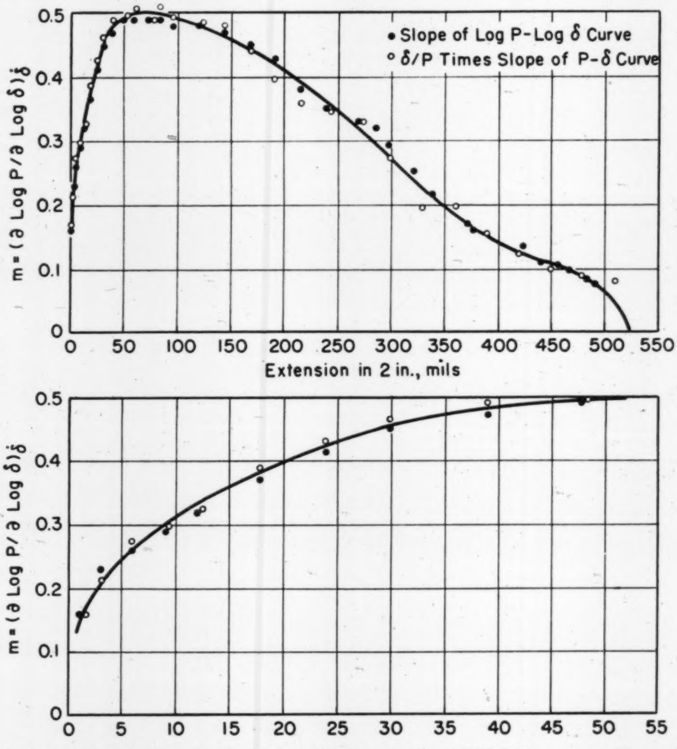

FIG. 11.—Variation of Strain-Hardening Rate with Strain for OFHC Copper at Room Temperature.

The values of rate sensitivity were obtained as before (1) and are summarized in Fig. 10. Most of the points in Fig. 10 represent the average of several *n*-values from several consecutive load changes, such as in curves Nos. 10, 22 or 30 of Fig. 7. There was a typical scattering of about ±10 per cent in the values that were averaged to obtain the points in Fig. 10. Figure 10 shows the same behavior as noted earlier (1): the rate sensitivity value determined from the rate change caused by a load decrement is larger than that corresponding to a load increment. The effect of the direction of load change on the rate sensitivity value is particularly clear in curve No. 36 of Fig. 7 and in the test of Fig. 8.

The early part of the trend curve in Fig. 10 has been drawn to conform to the data at small strains (1). The data points do not disagree with the trend curve for small strains, even though the grain size was smaller than that of the material of the earlier investigation.

The load-extension curve was obtained (7) by plotting creep extension at a given rate *versus* the corresponding creep load. From the slope of this curve, $m = [(\partial \log P)/(\partial \log \delta)]_{\dot{\delta}}$ can be obtained, using the relation:

$$\left(\frac{\partial \log P}{\partial \log \delta}\right)_{\dot{\delta}} = \left(\frac{\partial P}{\partial \delta}\right)_{\dot{\delta}} \left(\frac{\delta}{P}\right) \quad \ldots\ldots (2)$$

The value of m can also be obtained (7) from the slope of the log load - log extension curve; m-values obtained by both methods are shown in Fig. 11.

Figure 12 shows the load-extension data plotted in the more usual coordinates of true stress and true plastic strain; the earlier data (1) at small strains have also been included. The higher flow stress for the finer grain size is apparent from the figure. It appears that the two curves might cross at some sufficiently large strain. It has been observed earlier (12) that the stress-strain curves for different grain sizes actually do cross when carried out to large strains (Fig. 13).

The measured values of p (Fig. 6) were combined with m and n values from the trend curves of Figs. 10 and 11, re-

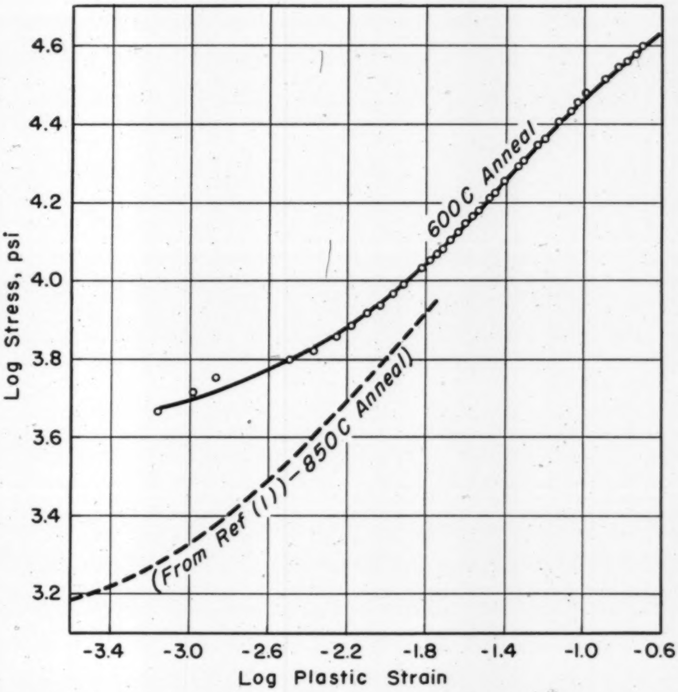

FIG. 12.—Stress-Strain Curve on Log-Log Coordinates for Certified OFHC Copper Cold-Drawn 84 per cent and Annealed 1 hr at 600 C, Compared with Previous Data (1) on the Same Copper with a Larger Grain Size. Ratio of grain sizes in the two specimens is about seven.

spectively, to form values of $-pn/m$, which have been plotted in Fig. 14. The results show that $-pn/m$ is definitely farther from unity (plastic ideality) if one uses n values associated with load decrements than if one uses n values associated with load increments (see also reference (**1**)). This fact strengthens the earlier conclusion that the concept of plastic ideality must be restricted to monotonic loading. Also, it should be noted that if the values of p corresponding to the filled triangles in Fig. 9 had been used in computing $-pn/m$, the $-pn/m$ values would be several times as large as those shown in Fig. 14. In other words, the creep behavior immediately following a small load decrement is not

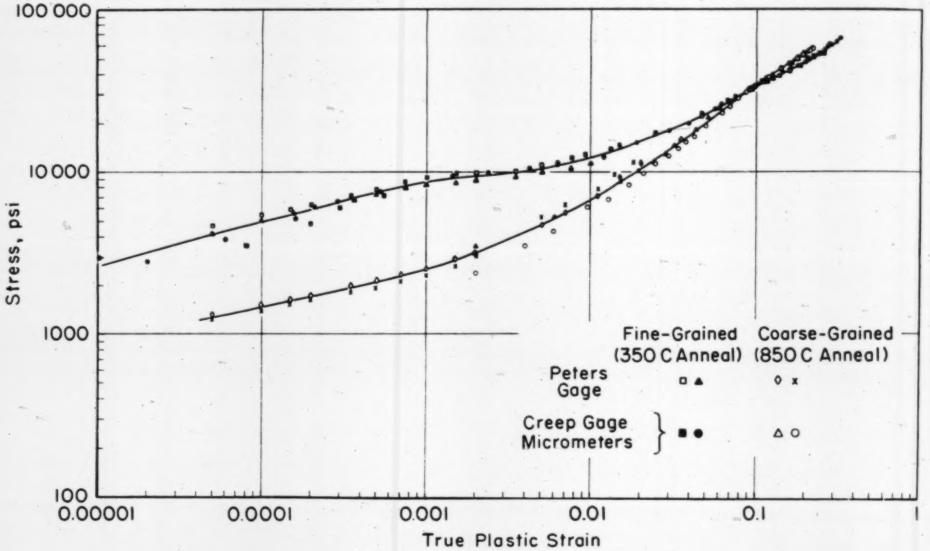

FIG. 13.—Effect of Grain Size on the Room Temperature Stress-Strain Curve of OFHC Copper. Coarse grain size = 35 times fine grain size. From Lubahn (**12**).

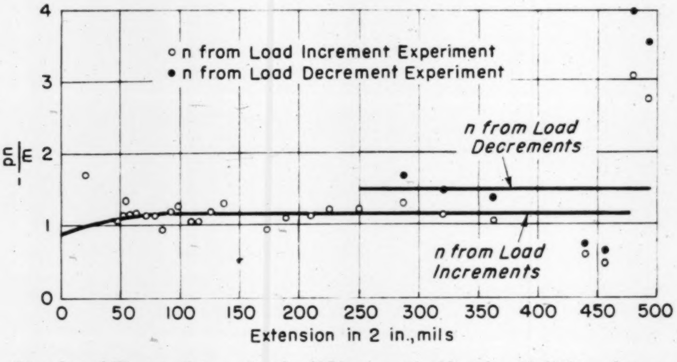

FIG. 14.—Results of Test to Large Strain (25 per cent), Showing Validity of $p = -m/n$.

close to ideal plastic behavior. Here again the need is clear for restricting the concept of plastic ideality to monotonic loading.

Except for strains greater than about 20 per cent, the open circles in Fig. 14 conform almost as closely to $-pn/m = 1$ as those at smaller strains (1), $-pn/m$ averaging about 1.15 or 1.2.[5] However, the departures of $-pn/m$ from unity are in the opposite direction. The discrepancy between $-pn/m$ and unity does not corespond to a very large error in the creep curve calculated from Eq 1 and from measured m and n values, as indicated in Fig. 15. The calculations are shown in the Appendix.

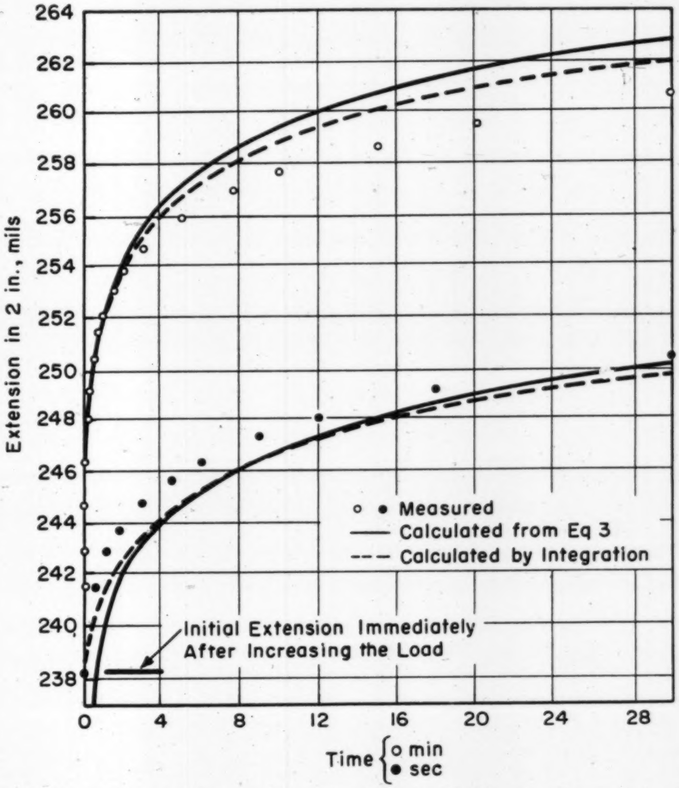

FIG. 15.—Calculated Creep Behavior Assuming Plastic Ideality As Compared with Measured Creep Behavior at a Rather Large Strain. Rate sensitivity determined from load increment experiment.

The conclusion from Fig. 14 is that for practical purposes the plastic behavior in copper at room temperature is ideal for monotonic loading—that is, the behavior depends only on the current conditions and not on past history. This result supports the earlier conclusion from tests at small strains (1). It is important to emphasize that this conclusion is applicable only to certain special conditions and not to the wide variety of conditions which may have been envisioned by previous investigators. (A) For any conditions where metallurgical changes occur, the metal will not behave in an ideal manner (10) nor would it be expected to do so (4). (B) Metals are plastically nonideal if strain is introduced at one temperature and then the deformation is observed at a different temperature. These "temperature-history" effects occur even at low temperatures, where metallurgical changes are absent (6, 13, 14, 15). (C) The results described above show that, if nonmonotonic loading occurs, plastic ideality will not prevail, even at lower temperatures where metallurgical changes are absent and where the temperature remains constant Nonmonotonic loading interferes with plastic ideality, because of the Bauschinger effect. (D) Under some conditions (16), isothermal behavior has been found to be nonideal, even when both metallurgical changes and the Bauschinger effect apparently are absent.

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[5] At large strains, p and m become small and, although the absolute scattering does not increase (see Fig. 6), the percentage scattering becomes very large in both p and $-pn/m$. In the limiting case of the inflection point of the creep curve, p and m both become zero, and $-pn/m$ is indeterminate.

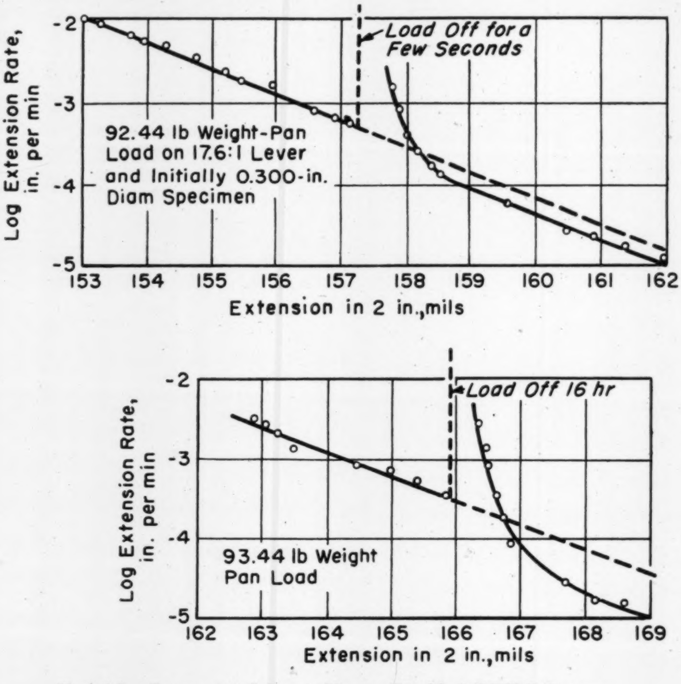

FIG. 16.—Interrupted Creep Tests. Certified OFHC Copper.

Figure 16 shows some typical interrupted creep tests at large strains, expressed as log extension rate *versus* extension. Three such tests were made in which the load was reapplied immediately, and three in which the load was left off for periods of 16 to 64 hr. The figure shows that the behavior is essentially the same at large strains as at small strains (1): the creep rate is abnormally large (specimen abnormally soft) immediately after reloading, but this effect (Bauschinger effect (17)) dies out eventually and the curve becomes parallel to an extension of that prior to unloading. After the dying out of the Bauschinger effect, the creep rate at a given strain is generally smaller than in the absence of unloading if the no-load period is long, but the creep behavior is identical on the average to that which would have prevailed in the absence of unloading if the duration of the no-load period is very short. Figure 17 summarizes the situation for the six tests at large strain as well as the three earlier small strain tests (1). This summary shows that four of the six tests unloaded for 16 hr or more showed that slight but definite strengthening (rate abnormally low) occurred during the no-load period. For immediate reloading, the average effect was nil; the apparent strengthening was small even when present (see upper graph of Fig. 16), and there appeared to be slight weakening of about the same magnitude in another test. The scattering in Fig. 17 probably corresponds to a horizontal shift of the log $\dot{\delta}$ - δ curve, due to failure of the gage to register precisely equal elastic strains on both loading and unloading.

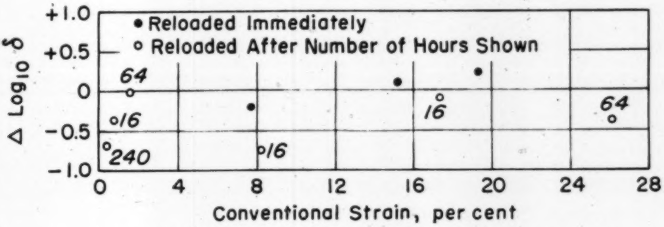

FIG. 17.—Summary of Results of Interrupted Creep Tests.

Taking n-values from Fig. 10, the strain aging effect in the six tests of Fig. 17 varies from 0 to 0.7 per cent in terms of stress and is 0.3 per cent on the average. Thus, the strain aging effect is so small that the results scarcely suffice to illustrate the effect, and certainly they cannot reveal the effect of prior strain or duration of the no-load period. In any case, Fig. 14 shows that the amount of strain aging observed does not significantly affect the ideality of the plastic behavior.

Acknowledgment:

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APPENDIX

CALCULATION OF CREEP CURVES FROM TENSION AND TRANSIENT DATA

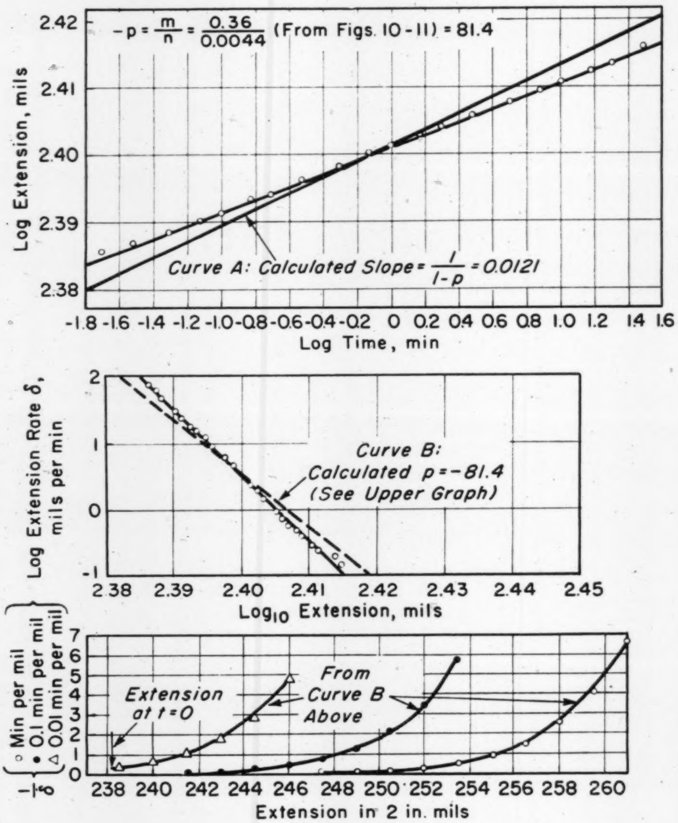

FIG. 18.—Detailed Calculations Used in Obtaining Fig. 15. Curve *A* illustrates the application of Eq 3, and the two lower graphs illustrate the more general integration method that must be used when the initial creep rate is finite.

At comparatively small load levels, a creep load or a creep load increment causes an initial plastic strain that is large compared to the subsequently measured creep strain, and the measured range of creep strain is rather narrow. Under these conditions, the creep curve can be calculated easily (**1**) by taking advantage of the fact (**5**) that both the log creep-strain *versus* log time and the log rate *versus* log strain curves are straight lines and that their slopes, a and p, respectively, are related by:

$$a = \frac{1}{1 - p} \quad \ldots\ldots\ldots\ldots (3)$$

The value of p is given by Eq 1 for the desired strain, and the corresponding a-value gives the slope of the log strain - log time curve in the neighborhood of that strain.

At larger load levels, particularly for small load increments, the initial creep rate is finite and measurable, as shown in Fig. 15. Under these conditions, Eq 3 is not strictly applicable, since it applies to a test where the load was constant from the zero of strain and implies infinite rate at zero time; and even though the log extension rate *versus* log extension curve were linear, the log extension *versus* log time curve would not be linear if the zero of time were taken at the instant of applying the most recent load increment. Under these conditions the strain-time curve must be obtained by constructing a log extension rate *versus* log extension curve whose slope is (m/n), and then integrating the reciprocal rate *versus* extension curve to obtain time, beginning at the initial extension of the test in question. Figure 15 shows that this method avoids what would be a substantial error near $t = 0$ if Eq 3 were used. Figure 18 illustrates both the use of Eq 3 and the integration method. It should be noted that the error near $t = 0$ due to the use of Eq 3 is appreciable, even though the log extension *versus* log time curve is very nearly linear.

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STRENGTH, DAMPING, AND ELASTICITY OF MATERIALS UNDER INCREASING REVERSED STRESS WITH REFERENCE TO ACCELERATED FATIGUE TESTING*

By F. H. Vitovec[1] and B. J. Lazan[1]

Synopsis

The purpose of the work was to investigate the damping, stress-strain, and failure properties under uniformly increasing stress amplitude and to determine the relation of these properties to conventionally determined fatigue strength. Data are presented on SAE 1020 steel, 2024-T4 aluminum alloy, SAE 4340 steel, and RC-55 titanium under rotating-bending stress amplitudes which (*a*) are progressively increased during the test, and (*b*) are held constant as in conventional fatigue tests. The Gough dynamic proportional limit method and the Lehr Method of damping intercept, under uniformly increasing stress amplitude were found to agree with the conventional fatigue strength only for certain materials and to be misleading in other cases. The failure stress at different rates of stress increase and different starting stresses was determined in order to evaluate the reliability of the Prot short-time fatigue testing method. For the materials tested, Prot starting stress below the cyclic stress sensitivity limit (in the region where damping is unchanged by stress history) has practically no effect on the Prot failure stress. In general, the test results for the four materials indicate that the Prot method indicates the conventional fatigue strength with a reliability of 10 per cent. The use of modified Prot methods which utilize loading rate exponents other than 0.5 were not significantly better for indicating fatigue strength.

The determination of the fatigue properties by the conventional Woehler method under constant stress amplitude may be very time consuming. Not only is it necessary to carry some specimens to large numbers of cycles, but also large numbers of specimens are sometimes required for statistically sound conclusions.

In view of the importance of reducing fatigue testing time, there has been considerable interest for over 40 yr in accelerated fatigue testing methods (**1**).[2] Most of the methods are based on the relationship between the fatigue strength and other physical properties of the material. The several methods investigated from 1920 to 1930 indicated that reliable results could be expected under certain conditions. Since some methods were

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[2] The boldface numbers in parentheses refer to the list of references appended to this paper, see p. 862.

useful only for certain materials and others could do no more than provide comparative results, interest in short-time fatigue testing methods decreased. Recently, however, Prot (**2**) proposed a new method which has renewed interest in accelerated test methods.

In the conventional fatigue test the load or strain amplitude is maintained constant until fatigue failure occurs, while in the progressive load increase (or Prot method) the load amplitude is uniformly increased until failure occurs. The rate of load increase is maintained constant during a given test, but may be different for different tests. In the Prot approach the mean values of the failure stress at each rate of load are plotted against the square root of the loading rate, and the fatigue limit is presumably obtained by extrapolating a straight line through these points to zero loading rate. In order to save time, Prot recommended starting the test at a stress approximately 6000 psi below the expected fatigue strength.

Prot based his method on the assumption that the S-N curve is a hyperbola which is asymptotic to the fatigue limit (**3**):

$$N = K(S - S_e)^{-m} \quad \ldots\ldots\ldots (1)$$

where:

N = cycles to failure,
S = reversed stress,
S_e = fatigue limit, and
K and m are materials constants.

Prot further assumed that the damage per cycle is proportional to the difference between the test stress and the fatigue strength. This difference increases with the number of cycles under progressive load increase, leading to failure stresses which lay on another hyperbola with the fatigue strength as the horizontal asymptote. This assumed relationship indicates that the failure stress under uniform load increase is a linear function of the square root of the loading rate:

$$S_R = S_e + K\sqrt{\alpha} \quad \ldots\ldots\ldots (2)$$

where S_R is the failure stress corresponding to the particular loading rate, α, in psi per cycle.

The interpretation of test results obtained from progressive load increase tests is not as simple as proposed by Prot since the effect of understressing (**4**) and of the nonlinearity of damage with respect to specimen life (**5**) must often be considered. Therefore, the Prot failure stress is not always a linear function of the square root of the loading rate as discussed above.

D. L. Henry (**6**) investigated the problem of failure under progressive load increase by using Miner's type of criterion for cumulative damage in fatigue (**7**), modified so that the sum of damage increments reach a value which may be different from unity. Like Prot, Henry used hyperbolic approximations for the conventional S-N curve and found that:

$$S_R = S_e + D\alpha^n \quad \ldots\ldots\ldots (3)$$

for:

$$n = \frac{1}{m + 1} \quad \ldots\ldots\ldots (4)$$

In Henry's method, the exponent n is determined from the constant m associated with the conventional S-N curve (Eq 4) while Prot assumed that n is 0.5 independent of the S-N curve.

The reliability of Prot's short-time fatigue testing method was the subject of several investigations (**8, 9, 10, 11, 12**). In general, it is found that Prot's method gives a good indication of the conventionally determined fatigue strength for ferrous metals with a well-defined fatigue limit. However, for nonferrous metals, such as aluminum alloys, the value of exponent n in Eq 3 which fits the experimental data best may differ considerably from 0.5. Furthermore, the fatigue strength determined from Eq 3 may differ considerably from the conventionally determined one.

Corten, Dimoff, and Dolan (**11**) investigated the effect of starting stress on the fatigue strength determined by the Prot method and found that in general, lower starting stresses resulted in a slightly lower value of the Prot fatigue strength. However, this work indicates that the effect of starting stress also depends on the type of material and its condition, being larger for metals "susceptible to coaxing."

Several other short-time fatigue testing methods based on properties under uniformly increasing alternating load have also been proposed (**1**). Among these are Gough's dynamic proportional limit criterion (**13**) and Lehr's damping intercept criterion (**14**).

In view of the conflicting observations made regarding the reliability of these three short-time methods for determining the fatigue strength from the progressive loading increase tests, the additional work described below was undertaken.

OBJECTIVES, PROCEDURES, AND TEST PROGRAM

The purpose of this program was to investigate the reliability of various progressive load increase methods for determining fatigue strength. Rotating-beam tests were used for this purpose so that the following three properties could be conveniently measured under uniformly increasing stress: (*a*) damping energy, (*b*) dynamic modulus of elasticity, and (*c*) failure stress. The damping properties were measured to check the reliability of Lehr's damping intercept criterion, the elasticity data were intended to check Gough's dynamic proportional limit method, and the failure stress data were determined to check the Prot approach.

In order to help clarify understressing and damage effects, various starting stresses were used. Progressive load increase tests were started at zero stress, near the cyclic stress sensitivity limit[3] for damping (**15**), and between this limit and the fatigue strength. For each starting stress, tests were performed under three different loading rates.

Two ferrous and two nonferrous materials were used to cover a range of material types and provide a more criticial check on reliability of conclusions. The materials used, starting stress, loading rate, and other details of the test program are given in Table I.

Conventional fatigue tests under constant stress amplitude were also performed for comparison purposes. The damping and modulus properties were also determined during these conventional fatigue tests.

TEST MATERIALS AND SPECIMEN PREPARATION

The test materials used in this investigation were SAE 1020 Steel, 2024-T4 aluminum alloy, SAE 4340 steel, and RC-55 titanium. The chemical analysis, treatment and test condition, and the mechanical properties of the test materials are listed in Table I.

The specimens used in this work were of circular cross section and slightly tapered to produce uniform stress along the test length under the cantilever beam loading used. The length of the tapered test section was 1.75 in. with 1 in. fillet radius on each end. The specimen diameters are listed in Table I.

The test specimens were rough turned from 0.05 to 0.01 in. oversize using water and oil as coolant, a speed of 325 rpm, a feed of 0.0042 in. per revolution, and a tool advance of 0.025 in. Finish turning was from 0.003 to 0.005 in. oversize for the 4340 and titanium specimens with

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[3] The stress which marks the beginning of stress history effects is called the cyclic stress sensitivity limit.

TABLE I.—TEST MATERIALS AND DATA.

	SAE 1020 Steel (Crucible Steel Co.)	2024-T4 Aluminum Alloy (Aluminum Company of America)	SAE 4340 Steel (Republic Steel Co.)	RC-55 Titanium (Rem-Cru Titanium)
Chemical composition	0.2 C, 0.45 Mn, 0.45 P, 0.055 S, Bal. Fe.	4.20 Cu, 1.66 Mg, 0.63 Mn, 0.30 Fe, 0.14 Si, 0.07 Zn, 0.02 Cr, 0.02 Ti, Bal. Al.	0.38 C, 0.74 Mn, 0.015 P, 0.021 S, 0.30 Si, 1.73 Ni, 0.75 Cr, 0.24 Mo, Bal. Fe.	0.045 C, 0.067 N, 0.0750, 0.0044 H, Bal. Ti.
Received as	Hot-rolled.	Hot-rolled, drawn.	Hot-rolled.	Hot-rolled, annealed.
Treatment after Receipt			Cyclic annealing; 1 hr, 1575 F, quench to 1225 F, hold for 16 hr, furnace to 1100 F, air. Double normalizing: 1 to ½ hr 1650 F, air. 1 hr, 1650 F, air. Quench: austenizing 1 hr, 1440 F, oil quench to 200 F. Temper: 1 hr 1054 F, air.	Forged at 1700 to 1800 F. Hot rolled at 1450 to 1550 F. Annealed 1 hr at 1300 F.
Modulus of elasticity psi	29.4×10^6	10.6×10^6		16.4×10^6
Yield strength psi	42 000	48 600	158 000	57 000
Tensile strength psi	69 000	72 800	160 000	75 000
Elongation, per cent	30	21.4	15	24.5
Reduction of area, per cent	60.5		57	25
Hardness	$R_B = 90$	$R_A = 48.5$	$R_C = 31.4$	$R_B = 88$
Specimen diameter, in.	0.375	0.585	0.375	0.25
Fatigue strength, psi	35 000	27 000	65 000	43 000
Loading rates, psi per cycle	0.0025	0.009	0.0025	0.01
	0.0250	0.027	0.0250	0.04
	0.0900	0.076	0.0900	0.09
Starting stresses, psi	0	0	0	0
	29 000	24 000		23 000
	33 000			34 000
	37 000			41 000

conditions similar to rough turning except for a 0.075 to 0.003 in. tool advance and a lower speed (45 rpm for the titanium). The SAE 1020 steel and 24-T4 aluminum specimens were left 0.02 in. oversize, then ground to 0.002 in. oversize using 120-06-V10 Aloxite wheels, a feed of 0.0015 in. per revolution and Tycol-Afton 8 as coolant. All specimens were finally polished using silicon carbide sanding belts, the final passes being with a belt having a grit size from 400 to 900. For the SAE 4340 specimens, kerosine coolant was used during final polishing and CO_2 was used for the titanium.

All materials were thermally treated before machining except that the 4340 steel was rough machined to 0.01 in. oversize, then heat treated, and finally finish machined and polished.

TESTING MACHINE AND TEST PROCEDURE

The rotating cantilever beam fatigue, damping, and elasticity testing machine used in this work has been described previously (16). For the progressive load increase tests, the machine was adapted with a variable speed transmission between the main motor and the table angle adjustor so that the desired rate of load increase could be applied to the test specimen. A photograph of the adapted machine is shown in Fig. 1. The variable ratio transmission, *T*, is driven by motor, *M*, which rotates the fatigue specimen, *S*, so that the stress increase per cycle during a progressive load increase test is independent of the frequency of stress on the specimen.

All the tests were performed at room temperature. The testing speed was 1000

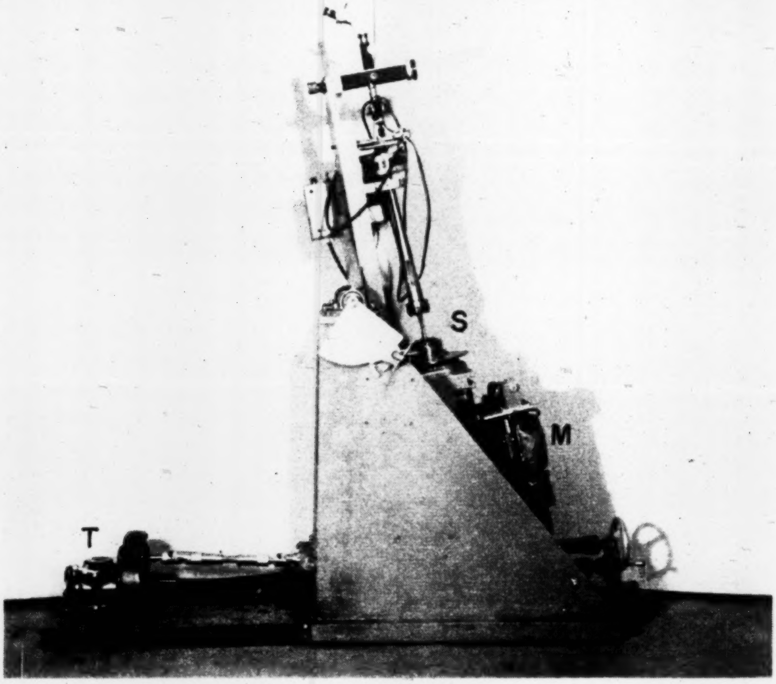

FIG. 1.—Rotating Cantilever Beam Fatigue and Damping Testing Machine with Variable Speed Transmission for Progressive Load Increase Tests.

rpm for 24-T4 aluminum alloy and RC-55 titanium and 2000 rpm for SAE 1020 and SAE 4340 Steel. In all cases the frequency of cyclic stress during damping and deflection readings was 20 rpm.

Conventional fatigue tests under constant stress amplitude were performed with the same type of testing machine and specimen as the progressive load increase tests.

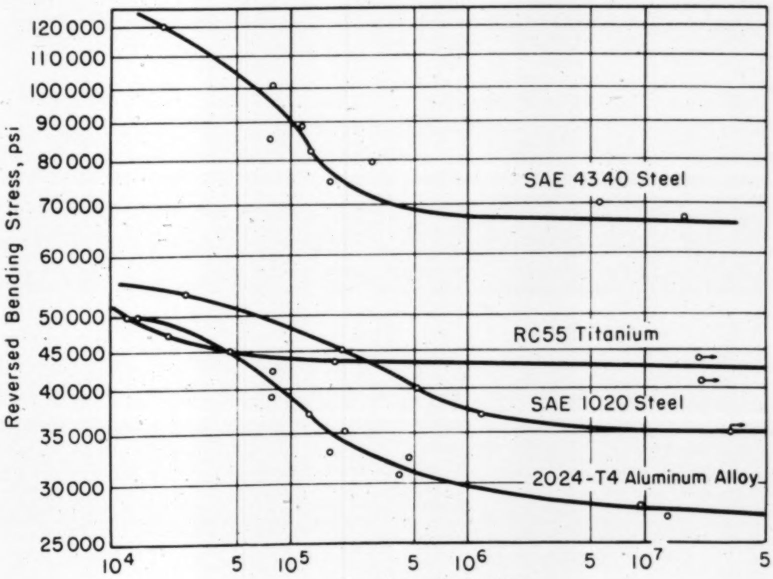

FIG. 2.—*S-N* Fatigue Diagrams of Test Materials.

FATIGUE AND DAMPING PROPERTIES UNDER CONSTANT STRESS AMPLITUDE

The *S-N* fatigue data procured under conventional constant stress amplitude conditions are plotted in Fig. 2.

During the course of each constant stress amplitude fatigue test, the damping energy absorbed by the test specimen was periodically determined. Typical data obtained for the four test materials are shown in Fig. 3. Under relatively low stress, the damping does not change with stress history (that is number of stress cycles) but as the stress approaches the fatigue strength then damping is affected by repeated fatigue stress. The four test materials diagramed in Fig. 3, showed different patterns of change during sustained cyclic stress: for example, the titanium and mild steel increase in damping with stress history, whereas the aluminum alloy decreases up to immediately before failure. However although the pattern of change at high stress amplitudes is different for different materials, it should be observed that all test materials have one behavior in common; damping does not change with number of cycles at low and intermediate stress amplitudes but is affected by sustained cyclic stress near and above the fatigue limit.[4]

The stress history dependence of

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[4] This observation has been made for numerous other materials (15). However it should be mentioned that RC-55 behaved rather erratically and did give some evidence of stress history effects at low stress amplitudes.

damping can better be seen in Fig. 4 which shows damping *versus* stress amplitude on a log-log basis. The stress history effects at high stress amplitude are shown in these diagrams by the family of curves for each material. For example, the curves labeled $10^{1.3}$ indicate the damping after 20 cycles and the curve labeled 10^3 gives the damping after 1000 cycles. Although these curves for the four different materials are quite dissimilar in many respects, they all display a cyclic stress sensitivity limit S_L (solid square dots, Fig. 4). Below this limit the log-log plot of damping *versus* stress curve is a single valued curve, usually a straight line, indicating no stress history effect. Above this limit, however, two changes generally occur. First the damping becomes not only a function of stress amplitude, but also of the number of prior stress cycles and thus a separate curve is required for each stress history. Secondly, a change in the slope generally occurs, in some cases quite abruptly. For the four materials under discussion, the cyclic stress sensitivity limit varies between 60 and 88 per cent of the fatigue strength at 2×10^7 cycles. The existence of a cyclic stress sensitivity limit has been observed not only in the four alloys under discussion, but in over ten others investigated to date, some at elevated temperatures (**15**).

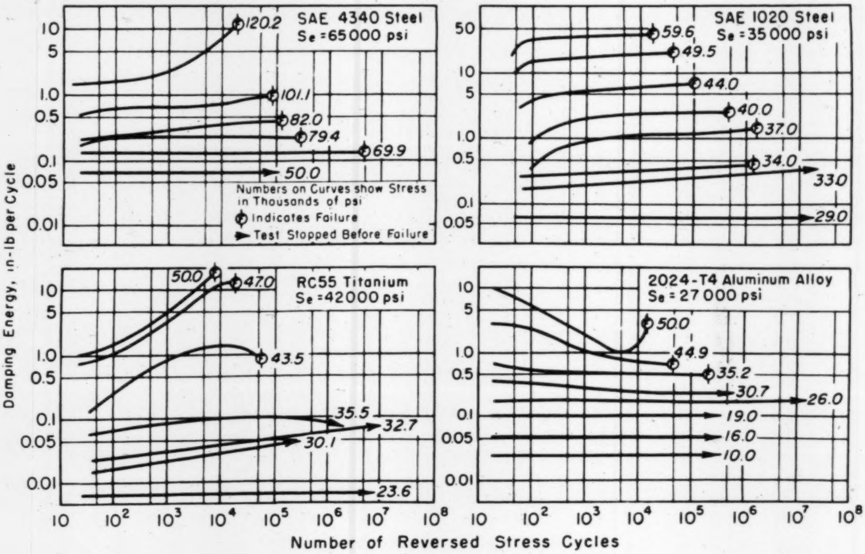

FIG. 3.—Comparison of the Effect of Cyclic Stress of Several Magnitudes on the Total Damping Energy of Test Materials.

In some materials, mild steel for example, both the change in slope and the effect of stress history on damping occur abruptly at a definite stress and the cyclic stress sensitivity limit is well defined. In other materials, such as in the aluminum alloy, these changes are much more gradual and the point defined as the stress sensitivity limit depends on the sensitivity of measurements. In this regard the difficulties in defining the cyclic stress sensitivity limit are similar to those encountered in defining a proportional limit under static stress.

The effect of stress history on the damping properties seem to be associ-

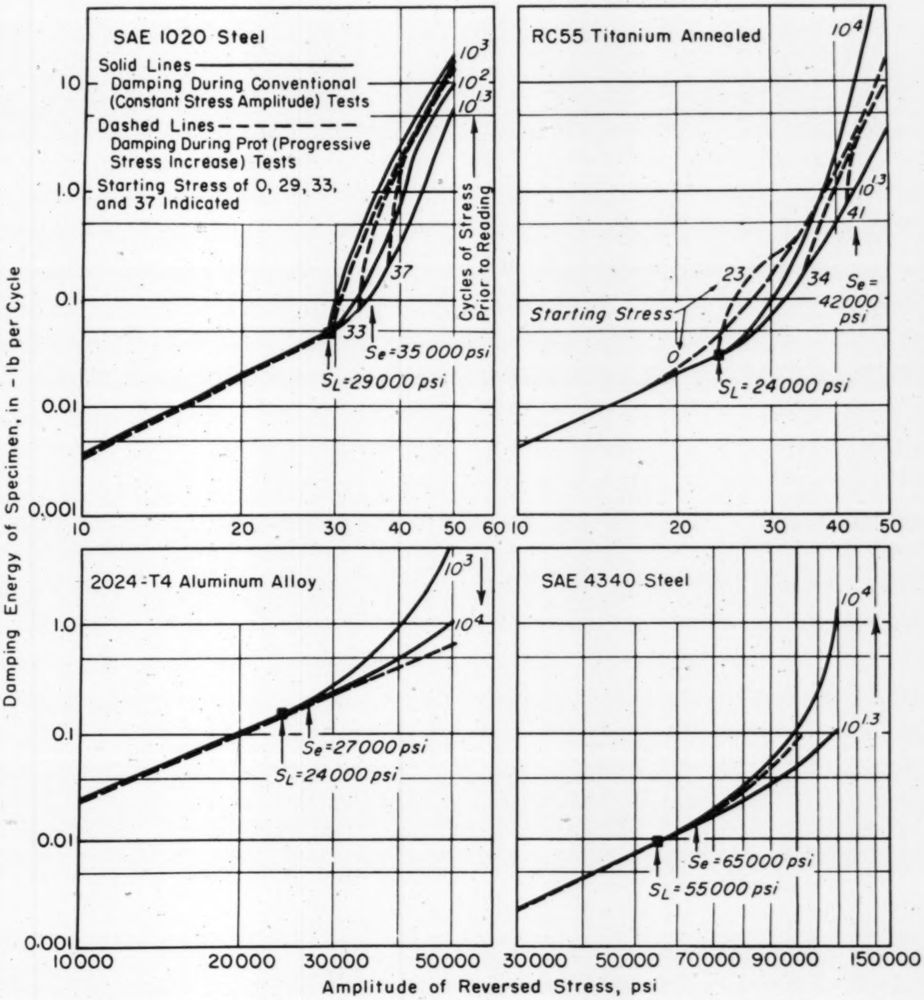

FIG. 4.—Total Damping Energy of Test Specimen Under Both Constant and Progressively Increasing Stress Amplitude as a Function of Stress for Various Stress Histories.

ated with localized plastic deformation. In polycrystalline materials, some grains which are favorably oriented and are in a critical stress condition yield plastically, preferentially near the surface (17) at stresses which are significantly below the overall fatigue strength. However, the per cent volume of those grains is very small and their effect may be lost in the general over-all observation. With increasing stress beyond the cyclic stress sensitivity limit the number of grains which yield plastically increases, slowly at first but with increasing rapidity. At stresses above the fatigue limit the per cent volume displaying significantly inelastic behavior is large enough to cause the large gross effects observed.

Since damping is an extremely structure sensitive property, it appears rea-

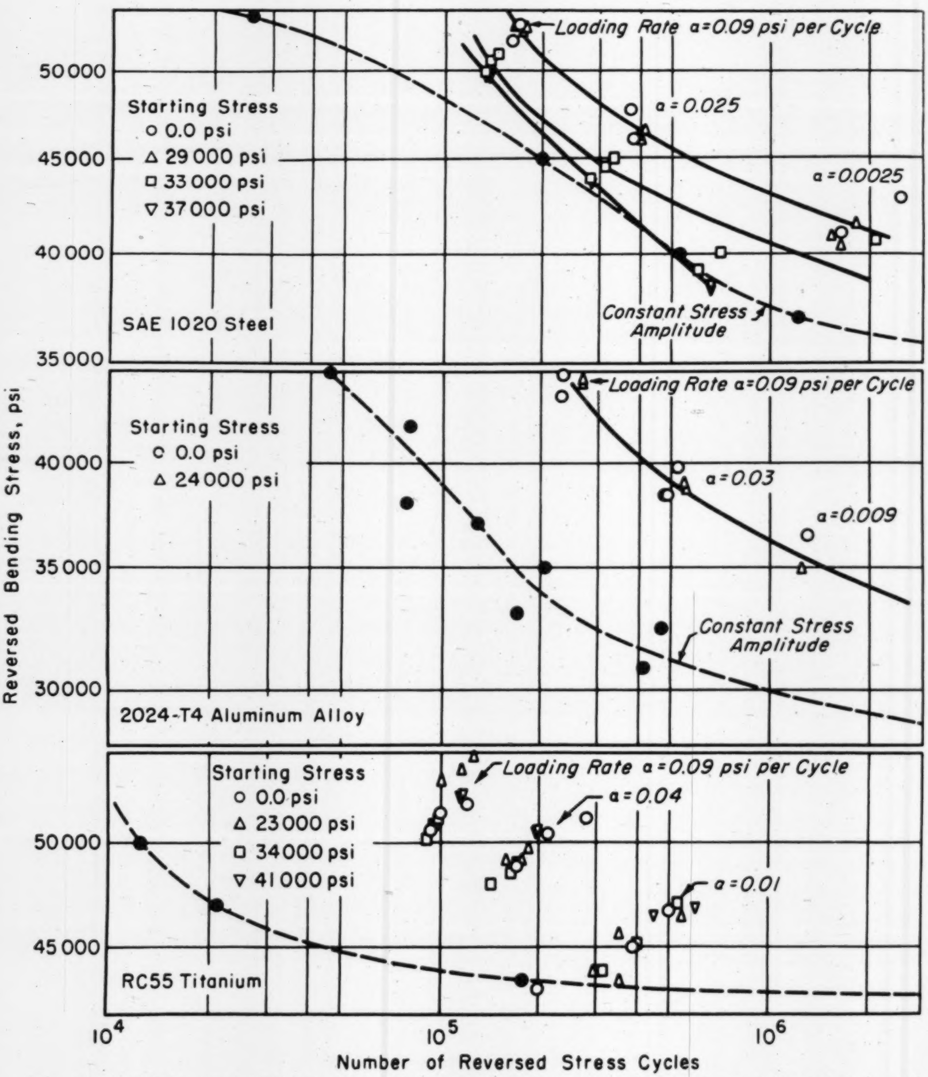

FIG. 5.—*S-N* Curves Obtained Under (*a*) Constant Stress Amplitude Conventional Tests and (*b*) Uniformly Increasing Stress Amplitude. Cycles Plotted are difference between total to fracture and those corresponding to the *Highest Starting Stress.*

sonable to inquire about the relationship between the cyclic stress sensitivity limit and the stress below which fatigue coaxing or damage becomes insignificant. One might expect that since cyclic stress below stress sensitivity limit has little effect on damping, correspondingly it should also have little effect on subsequent fatigue strength at higher stress levels. However, cyclic stress above this limit changes the material significantly, as indicated by the change in damping. It might therefore be expected that these changes would be reflected as fatigue coaxing or damage effects which might affect the fatigue life during subsequent loading at higher stress levels. Therefore, starting stresses both below and above this limit were used for some materials in the progressive load increase work described later.

FATIGUE STRENGTH UNDER PROGRESSIVE LOAD INCREASE

The fatigue strength test data procured under progressive load increase are plotted in Fig. 5. Different starting stresses were used in order to determine their effect on failure strength and also to clarify the relationship of coaxing and fatigue damage to the cyclic stress sensitivity limit.

Considering first the mild steel, the upper part of Fig. 5 shows the Prot failure stress determined at the different starting stress of 0, 29,000, 33,000, and 37,000 psi for different loading rates. The cycles to failure plotted for all curves are those imposed beyond the stress of 37,000 psi so direct comparison can be made for different starting stresses. Observe first that starting stress of zero and 29,000 psi have about the same Prot failure stress, indicating little coaxing or fatigue damage effect below the cyclic stress sensitivity limit. However, if the starting stress is 33,000 or 37,000 psi, the curves are significantly below those for the lower starting stress. This indicates that for stresses between 29,000 and 33,000 psi, and between 33,000 psi and 37,000 psi there is sufficient coaxing effect to produce the significant spread in the curves shown. For example, at a Prot loading rate of approximately 0.025 psi per cycle the fatigue failure stress for different starting stresses was 47,200 and 46,300 psi (avg 46,700 psi) at 0 psi starting stress; 47,000, 46,600, 46,400, and 46,500 psi (avg 46,600 psi) at 29,000 psi starting stress; 45,100, 44,700, and 44,000 psi

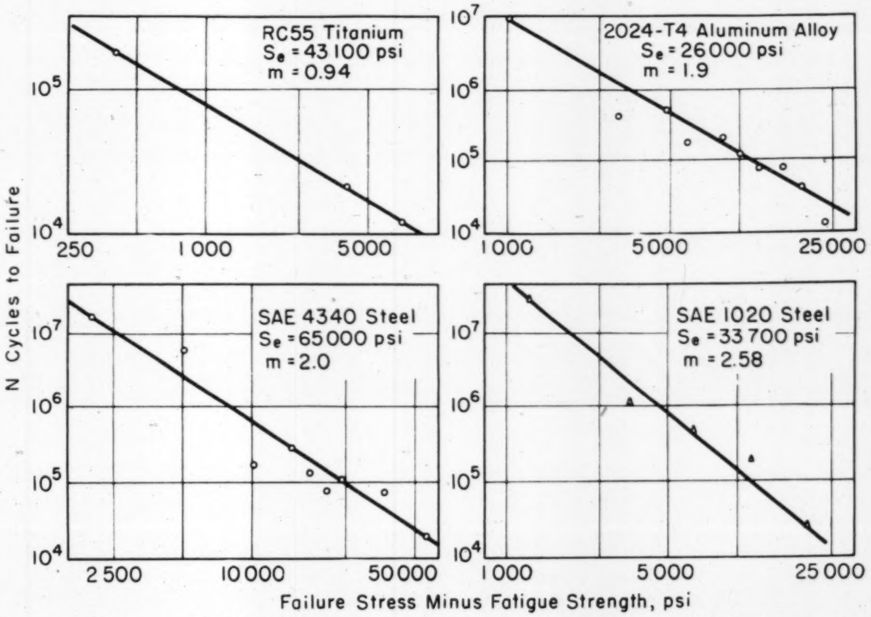

FIG. 6.—*N Versus (S-Se)* Diagram for Determination of the Constants in Weibul's Equation.

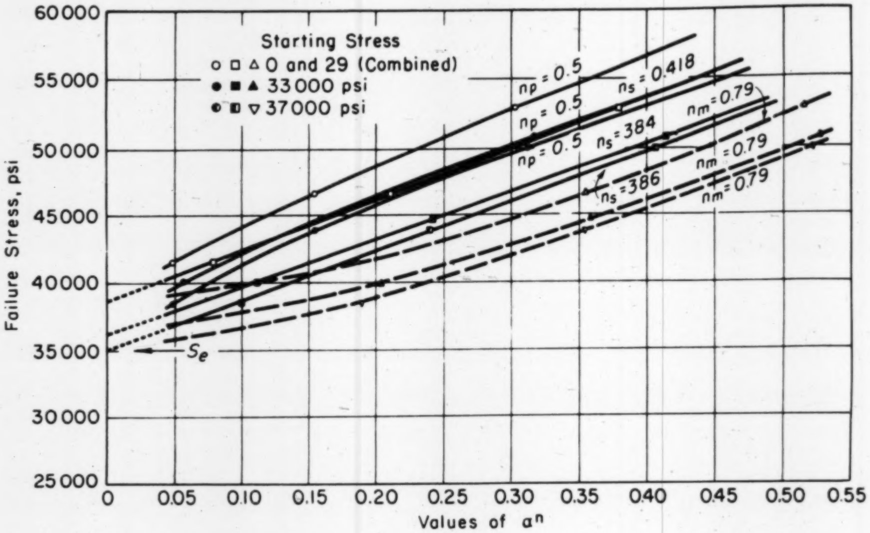

FIG. 7.—Failure Stress Under Progressive Load Increase as a Function of Loading Rate α to the Various Values of Power n for SAE 1020 Steel.

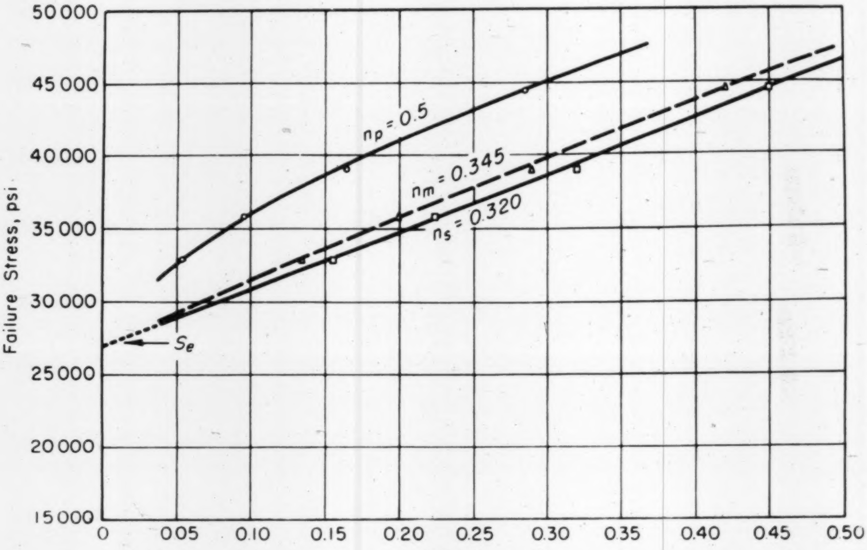

FIG. 8.—Failure Stress Under Progressive Load Increase as a Function of Loading Rate α to the Various Values of Power n for 2024-T4 Aluminum Alloy.

(avg 44,600 psi) at 33,000 psi starting stress; and 43,700, and 43,700 psi at 37,000 psi starting stress. The specimens started at zero and 29,000 psi failed at a higher stress than those started at 33,000 psi (failure stress 46,600 compared to 44,600 psi) apparently due to coaxing effects between 29,000 psi and 33,000 psi even though the fatigue limit is at 35,000 psi. Similarly stress history between 33,000 and 37,000 psi produced sufficient coaxing effect (or a combination of coaxing and damage) to account for the difference between the failure stress of 43,700 and 44,600 psi. Since the cyclic stress sensitivity limit is 29,000 psi, it appears that this limit incidates the stress below which no coaxing or fatigue damage effects occur but above which these effects may be significant in mild steel.

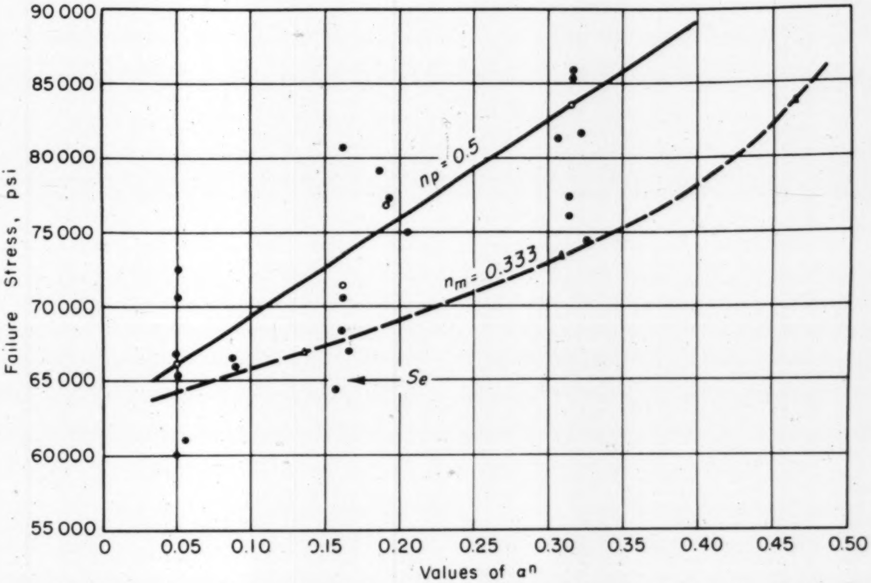

FIG. 9.—Failure Stress Under Progressive Load Increase as a Function of Loading Rate α to the Various Values of Power n for SAE 4340 Steel.

In the case of 2024-T4 aluminum, diagramed in Fig. 5, whether the test is started at 0 or 24,000 psi appears to make little difference in the Prot failure stress if cycles are counted beyond 24,000 psi in both cases. Since 24,000 psi is the cyclic stress sensitivity limit for this alloy, this limit appears to be the stress below which coaxing or fatigue damage are insignificant.

For the case of the RC-55 titanium shown in Fig. 5, the starting stress effects appear to be too small to be separable from the scatter in the data. If there are coaxing effects beyond the cyclic stress sensitivity limit of 24,000 psi, these are smaller than the scatter in the present data, and, therefore, no conclusions are possible at this time. In general the RC-55 data were more variable than for the other test materials.

In order to evaluate the reliability of Henry's modification of the Prot theory, the material constant m for each of the four test materials was determined as shown in Fig. 6. This constant m was then used to compute the value of exponent n in accordance with Eq 4. In the

Prot type diagrams which follow, this, computed values of n as well as others are used for comparison purposes.

The Prot type diagrams shown in Figs. 7, 8, 9, and 10 are intended to compare the effects of different values of n and starting stress. In each case, three values of n are plotted (*a*) n_p, the 0.5 value originally suggested by Prot, (*b*) n_s, the value of n which results in the straightest line for failure stress, and (*c*) n_m, the value of n determined from the constant m for the material.

For mild steel, aluminum alloy, and titanium, the plot failure stress under progressive load increase *versus* the square root of the loading rate (n_p = 0.5) does not result in a straight line. However, if a straight line is approximated through these points the Prot fatigue strength so determined is in all cases within ±10 per cent of the conventionally determined fatigue strength. For 4340 steel, the Prot method provides a better approximation of the convential fatigue strength, the difference being only 4 per cent.

If the Prot test data are plotted according to exponent n_s of the loading rate which results in the straightest line the fatigue strength so determined is in some cases considerably smaller than the conventionally determined fatigue strength, as shown by RC-55 titanium, Fig. 10.

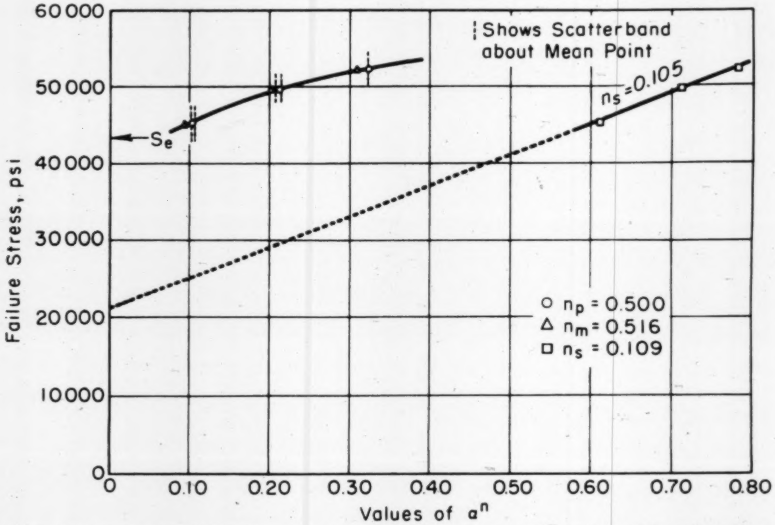

FIG. 10.—Failure Stress Under Progressive Load Increase as a Function of Loading Rate α to the Various Values of Power n for RC-55 Titanium.

The n_m values determined by Eq 4 from the constant m of the material differ in most cases from the two other values of n. In most cases n_m was different from the other values of n and appeared to offer no advantage. Theoretically the n_m value should produce straight-line relationship, but since this is not generally the case, the validity of Miner's criterion that damage is a linear function of the number of cycles at a given stress should be questioned.

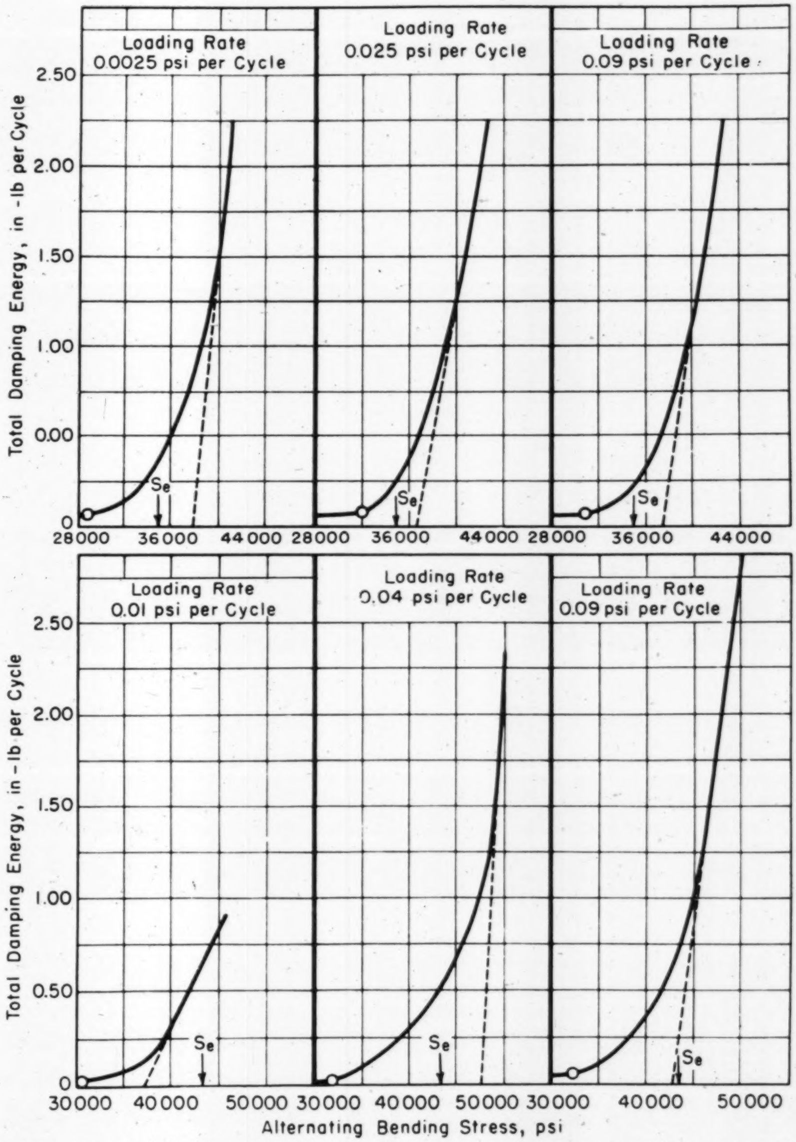

FIG. 11.—Linear Plot of Damping Energy *Versus* Alternating Stress at Different Loading Rates for SAE 1020 Steel (*top*) and RC-55 Titanium (*bottom*).

DAMPING PROPERTIES UNDER PROGRESSIVE LOAD INCREASE AND LEHR'S METHOD

Figure 4 shows damping energy *versus* stress amplitude considering both the constant stress amplitude and uniformly increasing stress tests.

The damping data of the SAE 1020 steel specimens indicate a cyclic stress sensitivity limit at 29,000 psi which is

83 per cent of the fatigue limit. Damping curves under progressively increasing stress, plotted in the same diagram show a sharp break at this cyclic stress sensitivity limit. There seems to be no effect of loading rate on the damping behavior for starting stresses up to the cyclic stress sensitivity limit. For starting stresses above this limit, damping increases more rapidly with increasing stress, as would be expected from stress history effects.

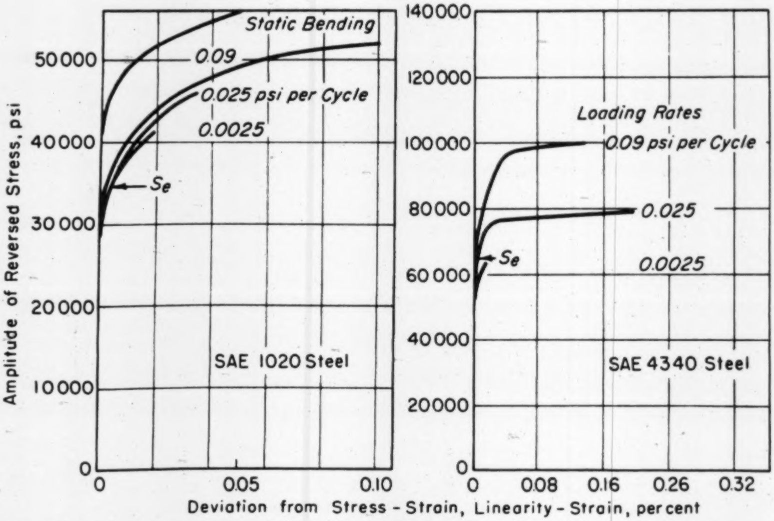

FIG. 12.—Deviation from Stress-Strain Linearity as a Function of Amplitude of Reversed Stress and Various Loading Rates for SAE 1020 and SAE 4340 Steel.

Fatigue tests at constant stress amplitude on 2024-T4 aluminum alloy show a cyclic stress sensitivity limit at approximately 24,000 psi, which is 89 per cent of the fatigue strength. However, damping curves during progressive load increase exhibit no such limit, the double logarithmic plot of damping *versus* stress being linear up to the failure stress. This also would be expected from the nature of the stress history effect.

SAE 4340 steel exhibits a cyclic stress sensitivity limit at approximately 55,000 psi, which is 15 per cent below the fatigue strength. The damping data under progressive load increase fall within the history band of the data obtained under constant stress amplitude.

The diagram for RC-55 titanium indicates that considerable history effects occur at stresses below the fatigue strength. In view of scatter in the data, the general trends are not conclusive. It is thus apparent from the above discussion that the damping *versus* stress relationship is very dependent on prior loading history.

In the short-time testing method suggested by Lehr (**14**) damping energy is plotted *versus* alternating stress to a linear scale. Lehr uses two different stresses as reference points, one which marks the beginning of the deviation of the curve from an approximate straight line in the low-stress damping range and a second which is obtained from the abscissa intercept of a line drawn tangent to the higher damping region of the damping stress curve. According to Lehr, the fatigue strength is near the lower stress limit for materials with a small initial damping, and near the higher stress limit for materials with a high initial damping. Considering what is now known regarding the nature of the damping *versus* stress relationship (**15**). The Lehr approach must be considered a rough approximation at best.

Figure 11 shows a linear plot of the damping energy - stress curve for SAE 1020 steel and RC-55 titanium. The diagrams for the steel and the location of the fatigue limit are in agreement with those published by Lehr. The diagram for titanium indicates a significant effect of the loading rate on the fatigue strength determined by Lehr's method. The highest loading rate, 0.09 psi per cycle, indicates a fatigue strength which is only 1 per cent smaller than the conventionally determimed fatigue strength, but at other loading rates there is considerable difference. For the aluminum alloy, Lehr's method cannot be applied since the change of damping is so gradual and no significant transition range can be observed. In the case of SAE 4340 steel the scatter of data was too large for use of the Lehr method.

In view of the stress history effects discussed above, the significance of the Lehr intercept method for determining the fatigue limit is very questionable.

EFFECT OF FATIGUE ON STRESS-STRAIN PROPERTIES AND GOUGH'S DYNAMIC PROPORTIONAL LIMIT METHOD

H. J. Gough (**13**) determined a dynamic proportional limit under reversed cyclic stress by measuring alternating strain during progressively increasing alternating stress. He found a linear stress-strain relationship below a certain stress, beyond which the strains increase more rapidly than the stresses. He suggested that this dynamic proportional limit is a good indication of the fatigue strength.

In order to show the proportional limit more clearly, the deviation from stress-strain linearity rather than total strain (elastic plus plastic) was plotted as a function of amplitude of reversed stress in Fig. 12. For the SAE 1020 steel specimens, the static proportional limit under bending stress was found at 41,000 psi. The dynamic stress-strain behavior depends on the loading rate, and as shown in Fig. 12, varies between 28,000 and 31,000 psi, increasing with increasing loading rate. The dynamic proportional limit averages 29,000 psi, which is approximately 8 per cent smaller than the fatigue limit. It is interesting to note that the dynamic proportional limit of mild steel is of the same magnitude as the cyclic stress sensitivity limit.

Figure 12 shows also the deviation from stress-strain linearity as a function of amplitude of reversed stress for SAE 4340 steel. The diagram indicates that the dynamic proportional limit is a function of the rate of increase of stress amplitude (hereafter called loading rate), decreasing with decreasing loading rate. The dynamic proportional limit for the loading rate of 0.09 psi per cycle is equal to the fatigue limit of this material, but is different at other loading rates.

Figure 13 shows the deviation from stress-strain linearity as a function of amplitude of reversed stress, loading rate, and starting stress for RC-55 titanium. The behavior of this material is rather unusual as explained previously. Both the static and dynamic proportional limit are smaller than the fatigue strength; in fact, the dynamic stress-strain diagram starting from zero stress indicates an increase of the bending modulus at low stress. Because of this

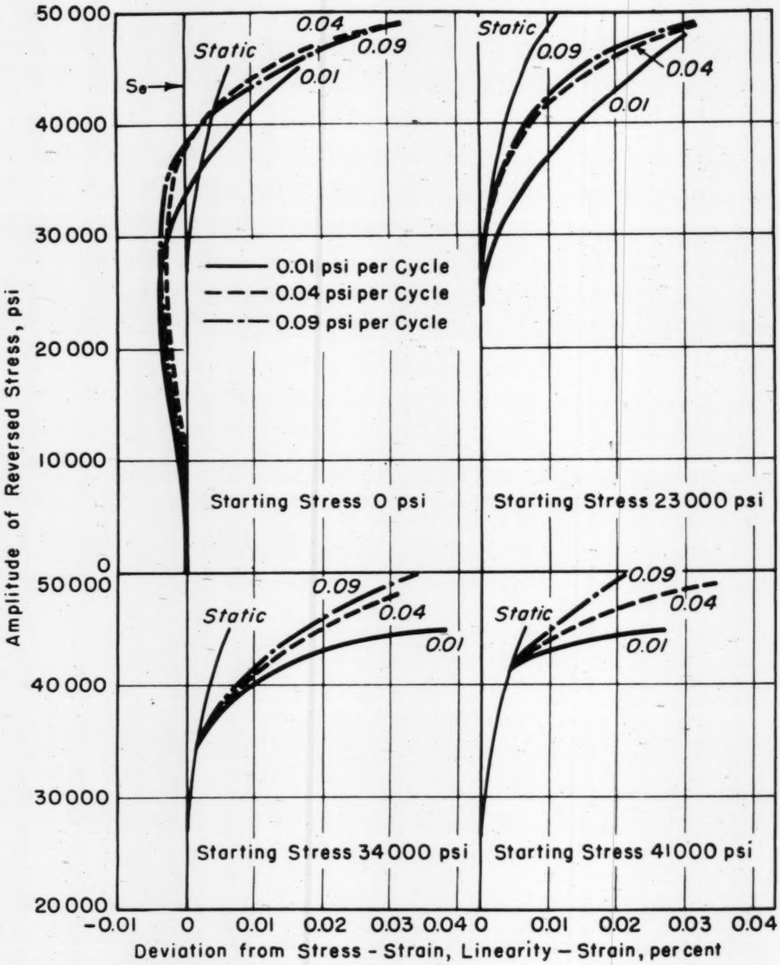

FIG. 13.—Deviation from Stress-Strain Linearity as a Function of Amplitude of Reversed Stress, Loading Rate, and Starting Stress for RC-55 Titanium.

behavior it is difficult to determine a definite dynamic proportional limit. The loading rate has a significant effect on the stress-strain behavior at all starting stresses. In general, the deformation at a given stress is increasing with decreasing loading rate.

For 2024-T4 aluminum alloy, the stress-deformation curve under both static load and progressively increasing alternating load remains linear up to 43,000 psi. This stress is far beyond the fatigue strength of 27,000 psi at 10^7 cycles of this material. These results show that the dynamic proportional limit of 2024-T4 does not indicate the fatigue strength.

It is apparent from the above that even though Gough's dynamic proportional limit method may give a reliable indication of the fatigue strength of some materials it may be misleading for many materials.

SUMMARY AND CONCLUSIONS

Tests under constant stress amplitude indicated that at low and intermediate stress amplitude the damping energy does not change with number of cycles, whereas when the stress amplitude exceeds a certain value, which is in general smaller than the fatigue strength, damping is a function of number of prior stress cycles.[3]

The following observations and conclusions may be made from the data presented for the materials tested:

1. Stress history below the cyclic stress sensitivity limit has relatively little effect on the fatigue strength properties. The magnitude of the starting stress is therefore insignificant as long as it is below the cyclic stress sensitivity limit. Starting stresses above this limit may result in significantly different failure stresses. RC-55 titanium may be an exception to this observation.

2. If the failure stresses obtained under progressive load increase are plotted *versus* the square root of the loading rate as suggested by Prot, a curve rather than a straight line is generally observed. However, if a straight line is approximated through these points the fatigue strength so determined is in all cases investigated within ±10 per cent of the conventionally determined fatigue strength.

3. If the Prot test data are plotted according to an exponent n_s of the loading rate which results in the straightest line the fatigue strength so determined may be considerably smaller than the conventionally determined fatigue strength.

4. According to Henry (6), the exponent n_m can also be determined from the conventional S-N curve. However, these values differ in most cases from the exponents determined by the two other methods and result in no improvement in indicating the conventional fatigue strength.

5. Lehr's damping intercept gives a fairly good indication of the fatigue strength of mild steel and titanium. However, the Lehr's criterion is a rough approximation and neglects the stress history effect.

6. Gough's method which is based on the dynamic proportional limit gives a fair indication of the fatigue strength for steel. Since 24-T4 aluminum alloy does not display a dynamic proportional limit in the stress range of interest. Gough's method is not suitable as he previously recognized. Since the dynamic proportional limit is a function of loading rate and increases with increasing loading rate, these factors must be considered in using this method.

7. Experimental data indicate Lehr's and Gough's methods are probably associated with the cyclic stress sensitivity limit.

8. All short-time fatigue testing methods using progressive load increase have serious limitations. However, Prot's method or extensions can be applied to a wider range of material types than the two other short-time testing methods investigated.

9. The titanium investigated in this work shows characteristics which differ in a few important respects from the other material. However, the Prot approach appears to be reasonably reliable for this material.

Acknowledgments:

The fine cooperation and encouragement of the Wright Air Development Center, sponsor of this work, is greatly appreciated.

N. Foker and F. Abigt served as technicians. Drafting work and manuscript preparation were by D. Schultz, H. Thomas and J. Whittier.

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DISCUSSION

Mr. K. Winterton.[1]—We were particularly interested in this paper because we have just begun some work using two non-destructive methods for examining the state of a metal from the point of view of micro-strains, or, if you like, tesseated stresses, and to follow the progress of that state during dynamic loading.

We have as a background idea, the conception that on an atomic scale there may be a limit to the capacity for energy absorption. Any dissipative mechanism, usually involving conversion of the energy to heat, will tend to delay the saturation of this capacity. We have chosen two methods to examine this possibility, firstly, an ultrasonic testing method in which we measure the attenuation of a pulsed ultrasonic beam, and, secondly, measurement of core losses using the Cyclograph. Perhaps a few remarks about the ultrasonic method will not be out of place since its use is more novel—particularly for commercial steels and for polycrystalline specimens.

With plain carbon steel (SAE 1020) we find on imposing a static tensile stress on a specimen that the attenuation is reduced; that is to say, less energy is transmitted. Why is that? We find that it is due to the magneto-mechanical linkage, and similar effects are obtained from a magnetic field. No such effects are found with aluminum or brass.

On cycling between zero and fixed loads, we find that the damping settles down after a few cycles and takes up a level which is characteristic of the given stress level.

Our present purpose is to look for evidences of permanent damage; that is to say, a change in the direction of increased micro-strains produced at stresses below the conventional static elastic limit.

Incidentally, one interesting consequence of this magneto-mechanical linkage is that with an ordinary carbon steel, there should be a reduction in the fatigue life if the test is carried out in the magnetic field, because in the ordinary case more of the energy is dissipated by heating due to eddy currents.

In this connection, E. R. Parker[2] discovered that in the presence of a strong magnetic field, the endurance limit was reduced by about 15 per cent, in some notched steel specimens. The fatigue life of specimens tested at various stress levels was affected in a similar way.

Messrs. F. H. Vitovec and B. J. Lazan (*authors*).—Mr. Winterton mentions that there probably is a limit to energy absorption by the material and that any dissipative mechanism, such as conversion to heat, will tend to delay the saturation. This appears to be a reasonable viewpoint. Unfortunately, however, it is extremely difficult to determine what per cent of the total energy input to the specimen (what is termed specific damping energy D in the paper) is dissipated as heat and what (probably very small) percentage is absorbed by the specimen and increases its energy level. We at the University of Minnesota are currently working on the problem of associating heat dissipation from a specimen under cyclic stress with temperature difference measurements. However, this method is insufficiently accurate at present to detect the small difference between energy input and heat dissipation.

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[1] Assistant Director, Department of Engineering & Metallurgy, Ontario Research Foundation, Toronto, Canada.

[2] E. R. Parker, "The Influence of Magnetic Fields on Damping Capacity," *Transactions*, Am. Soc. Metals, Vol. 28, Sept. 1940, pp. 661–670.

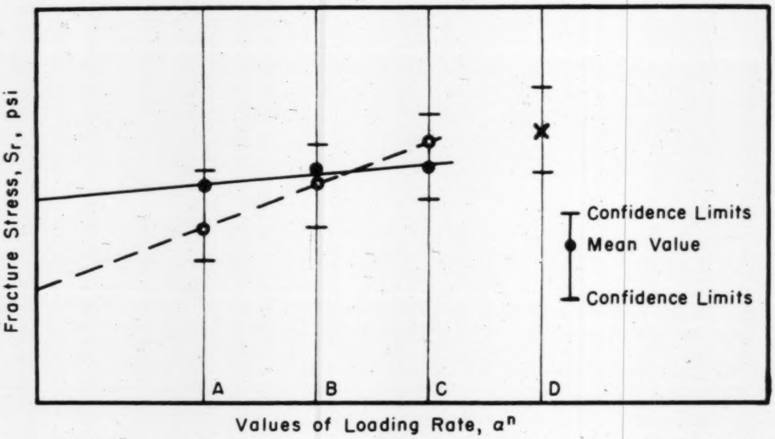

FIG. 14.—Possible Spread in Prot Data, Depending on Range Employed for Values of Loading Rate.

It should be mentioned that materials can continue to withstand large energy input for indefinite periods of time. One reported test, for example, remained unbroken after a billion stress cycles even though there was sufficient energy input to the specimen to maintain its temperature at 270 F during its life.

Mr. Winterton mentioned that he found that static mean stress reduces the attenuation of mild steel, apparently due to magneto-mechanical linkage. In recent and as yet unreported work at Minnesota we found that the damping of mild steel associated with a given alternating stress is unaffected by mean stress (as long as the maximum stress was below the cyclic stress sensitivity limit). Perhaps the differences in testing frequency and other test conditions could account for the difference in observation. Only for a highly magneto-mechanic material like type 403 alloy did we find a significant reduction in damping with prestress.

MR. T. J. DOLAN.[3]—When the Prot method was recently suggested, one of the main features seemed to be that one could expect to use fewer specimens to determine an appropriate endurance limit by testing a limited number of samples at only two or three different values of the loading rate, α. In looking at Mr. Lazan's data on titanium, it occurred to me that perhaps there is a feature of the Prot method that has not been fully recognized, which makes it desirable to employ many different values of α.

If one selects two or three values of the loading rate, α, and plots the data obtained on a curve of fracture stress *versus* loading rate as in the accompanying Fig. 14, one would suspect that because of the inherent statistical variability in fatigue data the mean fracture stress for any one value of α would fall over a range of stress levels. This range has been indicated by the horizontal bars for hypothetical 95 per cent confidence limits in the figure. For small groups of specimens, the mean value of fracture stress might then be obtained as indicated by the solid circles in Fig. 14. However, if a retest were made, new data might well be obtained such as that indicated by the open circles and dashed line in Fig. 14. The endurance limits obtained by extrapolation to $\alpha = 0$ could vary widely and differ somewhat from the true endurance limit, E. By using a wider range on values of α (as is indicated by the mean value X at loading rate D) the mean line through the points would tend to approach the true endurance limit E more closely when averaged with the previous data. Thus, it would seem most efficient to employ as wide a range in values of α as possible in order to eliminate some of the inherent spread obtained by the process of extrapolation. I do not believe that this fact has been pointed out in connection with the Prot method, but should be kept in mind when planning a new sequence of tests.

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[3] Head of the Department of Theoretical and Applied Mechanics, University of Illinois, Urbana, Ill.

MR. L. S. LAZAR.[4]—Seven values of α have been run for plastics at General Electric, and we find, as Mr. Dolan suggested, that we do get a better straight line; actually, alpha to the one-half power seems to give the best straight line. The extrapolation of this seems to be right where the endurance line is.

MESSRS. VITOVEC AND LAZAN.—Mr. Dolan points out that if n cannot be assumed at 0.5 then a wide spread in the range of values of α should be used. We certainly agree with this viewpoint. In fact, as we now view the matter, in the absence of a wide range of α values it is probably best to assume $n = 0.5$.

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[4] Development Engineer, General Electric Co., Schenectady, N. Y.

AN INVESTIGATION OF STRAIN AGING IN FATIGUE*

By J. C. Levy[1] and G. M. Sinclair[2]

Synopsis

Fatigue tests were performed on low-carbon steel at a rate of 2600 load cycles per min and at temperatures up to 700 F at a constant stress amplitude of 35,000 psi. A number of specimens, usually ten, were tested at each selected temperature, and the results were analyzed statistically. It was found that a peak in fatigue life occurred in the region of 450 F. There was a pronounced tendency for the scatter in life to increase as the mean life increased.

Subsequent tests established that the magnitude of the observed peak depended on the amount of carbon and nitrogen in solid solution. The effect could therefore be classified as one of strain aging which takes place during the course of the test. When both carbon and nitrogen were present, the peaking temperature was somewhat higher than when nitrogen alone was present, a fact which seemed to indicate an interaction between the two types of interstitial atoms.

A recently developed theory of strain aging has been applied in which carbon and nitrogen atoms are presumed to strengthen the metal by diffusing to dislocations in the crystal lattice. To apply this theory to fatigue conditions, the following assumptions were made:

1. The time available for aging was of the same order as the time of one loading cycle.

2. The distance to be travelled by the carbon and nitrogen atoms, in order to reanchor dislocations in fatigue affected zones, was 2×10^{-6} cm. (This corresponds to the distance they travel under tensile conditions and approximates the closest approach of dislocations in a heavily cold-worked metal.)

Utilizing these assumptions, the calculated peaking temperature agreed well with the observed value. A curve was constructed of the predicted temperature for peak life over a wide range of cyclic rates.

"Strain aging" is a familiar term used in connection with the recovery of the yield point in mild steel after tensile overstraining, and there are other instances in which it is known to exert an appreciable effect on mechanical properties. For example, steel exhibits a greater tensile strength at mildly elevated temperatures than it does at room temperature; this is attributable to strain aging occurring during the course of the test. It has been known for a number of years that strain aging is directly related to the presence of carbon and nitrogen in the steel. Under suitable circumstances, extremely small amounts of either element are sufficient to produce the effect (**1, 2**).[3] During conditions of repeated loading, there are certain types of behavior that recently have been associated with the aging of affected portions of the material. It has been shown (**3**) that materials capable of strain aging may readily be "coaxed" (that is, run for large numbers of cycles at several successively increasing values of stress) to a much higher fatigue strength than they were formerly known to possess. Again, when such materials are tested by the Prot method to establish their endurance limits, the results may be affected by aging occurring while the test is in progress (**4**).

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* Presented at the Fifty-eighth Annual Meeting of the Society, June 26–July 1, 1955.

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[2] Research Associate Professor, Dept. of Theoretical and Applied Mechanics, University of Illinois, Urbana, Ill.

[3] The boldface numbers in parentheses refer to the list of references appended to this paper, see p. 886.

The development of fatigue damage is, by its nature, a relatively long-time phenomenon during which plastic deformation occurs in highly localized regions. It is to be expected, therefore, that if a material is capable of strain aging, it will do so in these deformed regions when subjected to repeated loading.

There appear to have been no attempts made to correlate quantitative knowledge of strain aging with knowledge of fatigue properties. Such a project was thought to be profitable because of recent advances in the theory of strain aging made by researchers in the field of metal physics.

Purpose of Investigation:

The observation that some steels, notably those in the low-carbon category, appear to have greater fatigue strength in the range 400 to 500 F than at room temperature, has been reported by several investigators (**5, 6**). The purpose of the present work was to investigate this elevated-temperature behavior using statistical methods which lend assurance to the analysis of results. The eventual aim was to compare, both qualitatively and quantitatively, the observed elevated-temperature behavior with that deduced from strain-aging theory.

From the qualitative standpoint, the aim was to isolate the effect of strain aging on fatigue life by modifying the carbon and nitrogen contents of the metal. Quantitatively any basic correlation between fatigue strength and strain-aging properties necessarily involves the comparison of experimental fatigue results with the predictions of strain-aging theory, so that the purpose of this part of the investigation was:

1. To suggest methods for utilizing strain-aging theory to take account of repeated loading conditions. This part of the work is contained in the Appendix.[3a]

2. To examine the agreement between theoretical and experimental results in order to assess the validity of the application of strain-aging theory to this problem and, by inference, to other fatigue phenomena which may be caused by aging such as coaxing, the effect of rest periods on fatigue strength, the occurrence of a sharp "knee" in the *S-N* diagram, etc.

Scope of Tests:

Three batches of metal were tested in reversed bending at selected temperatures up to about 700 F. The first batch consisted of annealed low-carbon steel. The second batch was of the same steel treated to reduce the carbon and nitrogen contents and hence minimize the strain aging effects. The third batch was given the same treatment as the second but was also given a subsequent treatment to restore nitrogen to the lattice and therefore to reintroduce strain-aging ability. The same cyclic loading rate was used for all tests.

It was decided not to try to establish the endurance limit for each batch at each selected temperature because of the length of time and quantity of specimens required for such an operation. Instead, a stress of 35,000 psi (which was above the endurance limit at room temperature) was chosen, and all

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[3a] See p. 884.

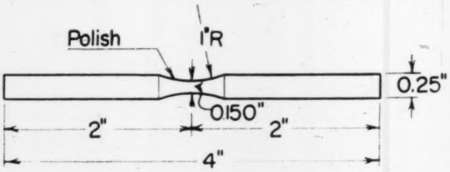


FIG. 1.—Rotating-Beam Fatigue Specimen.

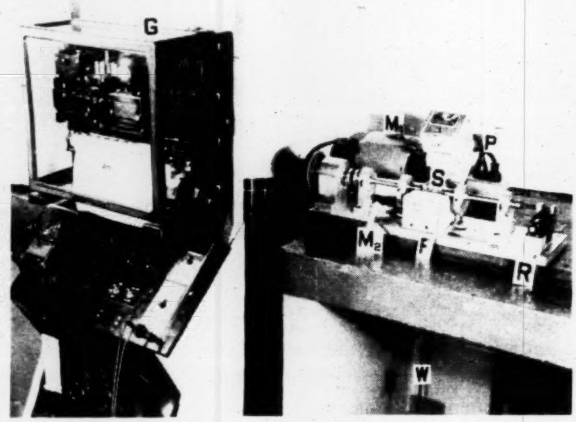


FIG. 2.—Rotating-Beam Fatigue Machine.

F—furnace.
G—temperature controller
P—mains point
M_1—motor
M_2—microswitch
R—revolution counter
S—specimen
W—weight hanger

specimens were run at this nominal stress. The performance was judged on the basis of the number of cycles to fracture.

To provide sufficient data for reliable statistical comparison of the mean life at one temperature with that at another, a number of specimens (usually ten) were tested under each chosen condition. As a subsidiary phase of the work, an examination was made of the variability in fatigue life through the temperature range.

TEST APPARATUS AND PROCEDURE

Material Used and Preparation of Specimens:

The material used for the series of tests was a ¼-in. diameter SAE 1018 cold-rolled rod having the following nominal chemical composition:

Carbon, per cent	0.15 to 0.20
Manganese, per cent	0.60 to 0.90
Phosphorus, per cent	0.04 max.
Sulfur, per cent	0.05 max.

The specimens were machined to the form and dimensions shown in Fig. 1. The reduced sections were polished longitudinally with No. 0 followed by No. 00 emery polishing paper.

Subsequent heat treatment was of three kinds:

Batch No. I—Heated in an inert atmosphere of helium at 1300 F for 24 hr, then furnace cooled.

Batch No. II—Heated in an atmosphere of wet hydrogen at 1300 F for 4 days. The purpose of this treatment was to reduce the carbon and nitrogen content of the steel and thus to minimize the strain-aging properties of the material.

Batch No. III—Same treatment as batch No. II but the specimens were reheated to 1300 F for 24 hr in an atmosphere of ammonia and again furnace cooled, the purpose being to reintroduce nitrogen and hence strain-aging characteristics to the steel.

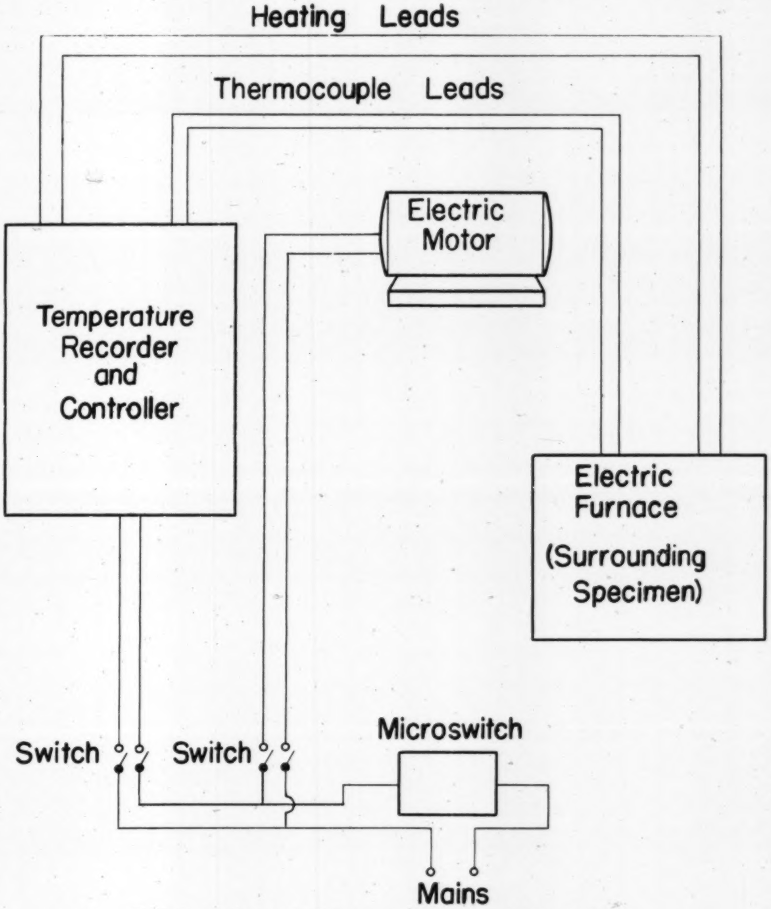

Heating Leads
Thermocouple Leads
Electric Motor
Temperature Recorder and Controller
Electric Furnace (Surrounding Specimen)
Microswitch
Switch
Switch
Mains

FIG. 3.—Schematic Diagram of Electrical Connections.

The motor drives the specimen through a belt and pulley arrangement. The microswitch automatically breaks the heating and motor circuits when the specimen fails.

In order to determine the success of the various heat treatments, a sample from each batch was polished and etched and photomicrographs (× 150) of the various crystalline structures were prepared.

Testing Machine and Calibration:

The fatigue tests were carried out on the specially-built rotating-beam machine shown in Fig. 2. The beam was simply supported at the ends and loaded by dead weights at the third points so that there was a constant bending moment over the central section. The grips were machined to accommodate a $\frac{1}{4}$-in. diameter specimen, and drive was provided by an electric motor through a belt and pulley arrangement, giving the machine a speed of 2600 rpm.

The machine was calibrated for load by measuring, weighing, and balancing the separate parts. The bending moment at the test section due to the tare weight of the machine was then calculated, and the result taken into account in computing the magnitude of extra weights to be added to obtain the specified stress at the test section.

The temperature of the specimen was controlled by means of an electric furnace fitted over the central portion of the beam. Current to the furnace was regulated by a Leeds and Northrup "Micromax" temperature regulator and recorder. Automatic shut-off of electricity, on breakage of specimen, was provided by arranging for the falling beam to trip a microswitch connected to both the heating and motor circuits. The electrical connections (Fig. 3) show that the heating and motor circuits could be operated separately when the microswitch was "on" but, when this switch was "off," both circuits were dead. This arrangement allowed the specimen to be brought up to a predetermined temperature before the fatigue loading was initiated.

Temperature calibration was carried out by placing a specimen in position with a thermocouple spot-welded to the test section, the leads being connected to a potentiometer. With the furnace closed, simultaneous readings were taken of furnace temperature, as indicated on the "Micromax" recorder, and of thermocouple emf as indicated on the potentiometer. The corresponding temperature at the surface of the specimen was then found from the emf reading.

Test Procedure:

Exploratory tension tests were carried out after the various heat treatments had been completed, the specially machined tension specimens having been heat treated with the various batches of material. The data on these tests are given in the next section.

For the fatigue tests, the diameter of the minimum section of the specimen was measured with a hand ball-point micrometer and the load calculated to give the desired nominal stress at the minimum section according to the ordinary flexure formula:

$$S = Mc/I$$

where:

S = stress at the outer fiber in psi,

M = bending moment applied in lb-in., and

I/c = section modulus at the critical section in in.^{3}

After the specimen had been mounted in the machine, the concentricity of the assembly was verified by the use of an Ames dial gage. Supports were placed under the beam to prevent bending of the specimen while it was being heated and, with the furnace closed, the heating circuit was switched on. After the furnace was up to the preset temperature, 30 min were allowed for the specimen to reach thermal equilibrium. The motor circuit was then switched on, the supports removed, and the machine loaded.

Statistical Procedure:

All statistical calculations were based on the assumption of a log-normal distribution for cyclic lifetimes under any particular set of conditions. That such a distribution is approximately valid has often been observed (7). Since only about ten specimens were tested under each condition, a "small sample" analysis was employed.

Means and Confidence Limits.—The mean of each set of results was calculated as the number of cycles corresponding to the mean value of log N, that is:

$$\log \bar{N} = \frac{\Sigma(\log N)}{n} \quad \text{..........} (1)$$

where:

$\bar{N}$ = required mean value of fatigue life,

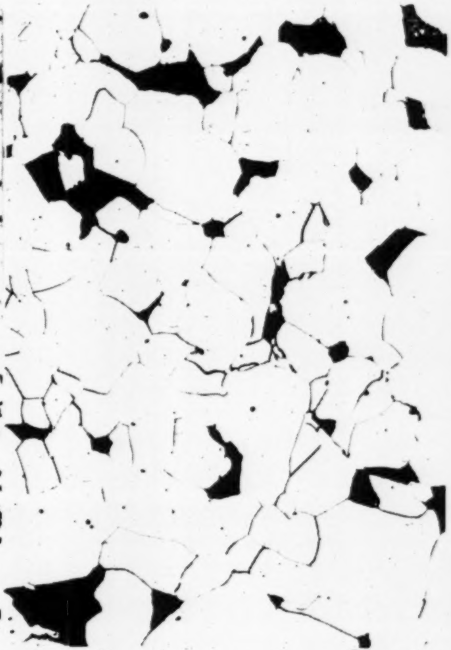
N = number of cycles to fracture,

n = number of specimens in the set, and

Σ denotes summation.

FIG. 4.—Material As Received (× 150).

FIG. 5.—Batch No. I—Helium Treated (× 150).



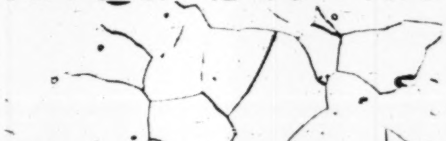


FIG. 6.—Batch No. II—Wet Hydrogen Treated (× 150).

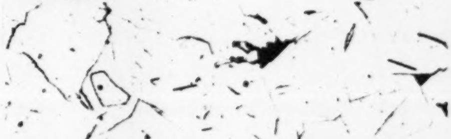


FIG. 7.—Batch No. III—Wet Hydrogen Treated, Then Ammonia Treated (× 150).

The confidence limits for any set of results specify the range within which there is a certain probability of finding the true value of the mean as determined by the sample and according to the distribution law which has been assumed.

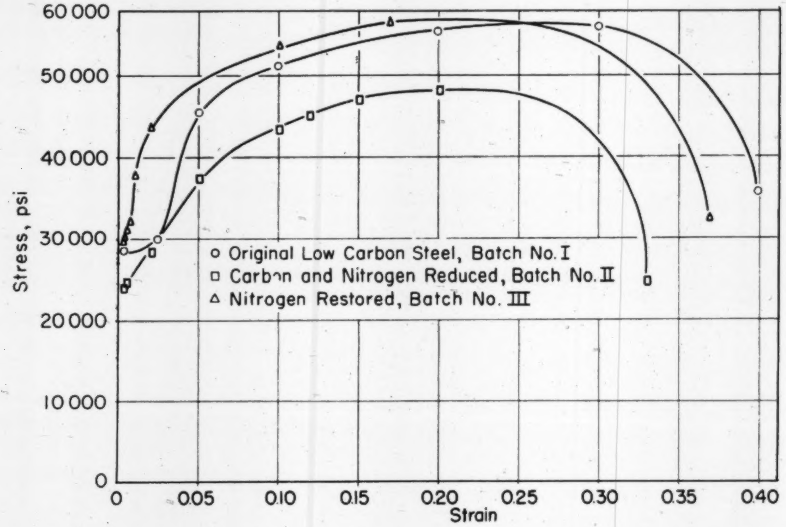


FIG. 8.—Tension Stress-Strain Curves After the Various Treatments.

If the upper and lower confidence limits are N_u and N_L, respectively, then:

$$\log N_u = \log \bar{N} + \frac{t\sigma}{\sqrt{n}} \qquad \text{.......(2)}$$

$$\log N_L = \log \bar{N} - \frac{t\sigma}{\sqrt{n}} \qquad \text{.......(3)}$$

where σ = standard deviation of the set, that is:

$$\sigma = \sqrt{\frac{\Sigma(\log \bar{N} - \log N)^2}{n - 1}}$$

and t is Student's "t" for which tables are available (8).

Comparison Between Sets of Lives.—Since the investigation was concerned with the detection of strengthening due to strain aging, it was necessary to decide whether the results at one temperature were significantly different from those at another, that is, to estimate the chance of the two sets being drawn from the same population.

The method used was to compare the means of the two sets through the value of Student's "t" in order to establish the level of significant difference between them. (Subscripts 1 and 2 refer to the two sets of results being compared.) For this case, "t" is defined by:

$$t = \frac{\log \bar{N}_1 - \log \bar{N}_2}{\lambda} \sqrt{\frac{n_1 n_2}{n_1 + n_2}} \qquad \text{....(4)}$$

$$\text{where: } \lambda^2 = \frac{\Sigma(\log N_1)^2 - \dfrac{(\Sigma \log N_1)^2}{n_1} + \Sigma(\log N_2)^2 - \dfrac{(\Sigma \log N_2)^2}{n_2}}{n_1 + n_2 - 2}$$

$$= \frac{X_1 + X_2}{n_1 + n_2 - 2} \text{ for convenience} \qquad \text{..(5)}$$

where X_1 and X_2, respectively, are the first and second pairs of terms in the numerator of the line above. For additional details, see Brownlee (8).

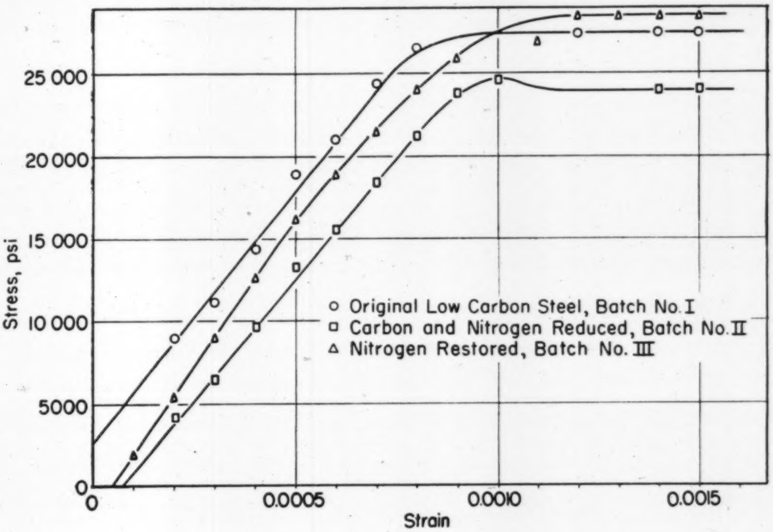


FIG. 9.—Tension Stress-Strain Curves (Early Portions).

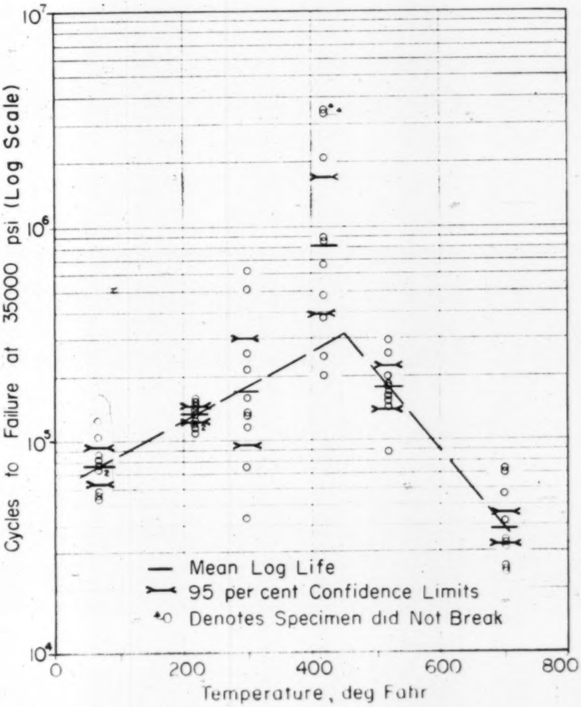


FIG. 10.—Test Results for the Original Low-Carbon Steel (Helium Treated).

RESULTS AND DISCUSSION

Microstructure:

A photomicrograph of the material in the as received condition is shown in Fig. 4. In Figs. 5 to 7 are shown the material designated as batches Nos. I, II, and III, respectively.

It will be seen from Fig. 5 that ample carbon was present in batch No. I to cause strain-aging effects, whereas in Fig. 6 the lower concentration of carbon in batch No. II is confirmed by the absence of pearlite. Nitride needles may be seen in Fig. 7, indicating that sufficient nitrogen had been reintroduced to batch No. III to permit strain-aging effects to occur.

Tension Tests:

Tension stress-strain curves for the three batches of material are shown in Fig. 8. The early portions are reproduced to a more convenient scale in Fig. 9.

Batch No. I shows the characteristic 2 per cent plastic elongation at the yield point of low-carbon steel. The value of the yield point was 27,500 psi, and the ultimate stress was 56,000 psi, the total elongation on a 1-in. gage length being 40 per cent.

In batch No. II a slight indication of a yield point remained. The 0.2 per cent yield strength was 24,000 psi, the ultimate stress was 48,200 psi, and the total elongation on a 1-in. gage length

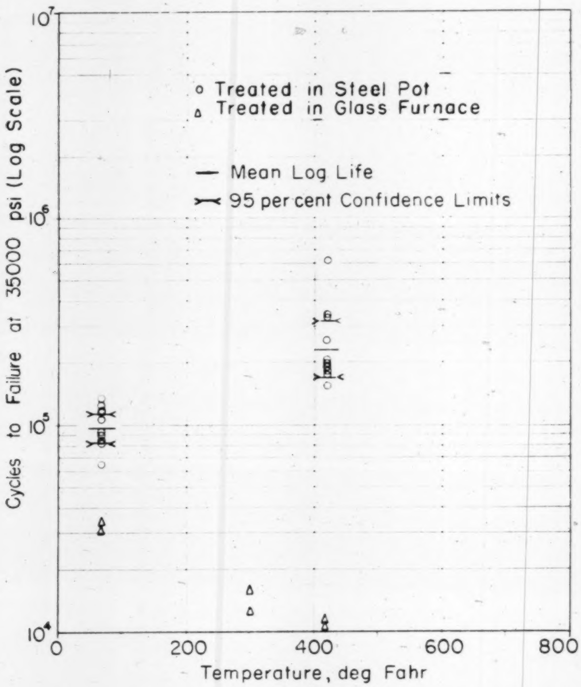


FIG. 11.—Test Results for Specimens with Carbon and Nitrogen Reduced (Wet Hydrogen Treated).

was 33 per cent. The alteration of the sharp yield point effect is a consequence of the removal of carbon and nitrogen and is consistent with the strain-aging concept described in the Appendix.

There is a small but definite plastic elongation at the yield point in the stress-strain curve for batch No. III. The yield point was 29,600 psi, and the ultimate stress was 56,400 psi. The total elongation on a 1-in. gage length was 37 per cent.

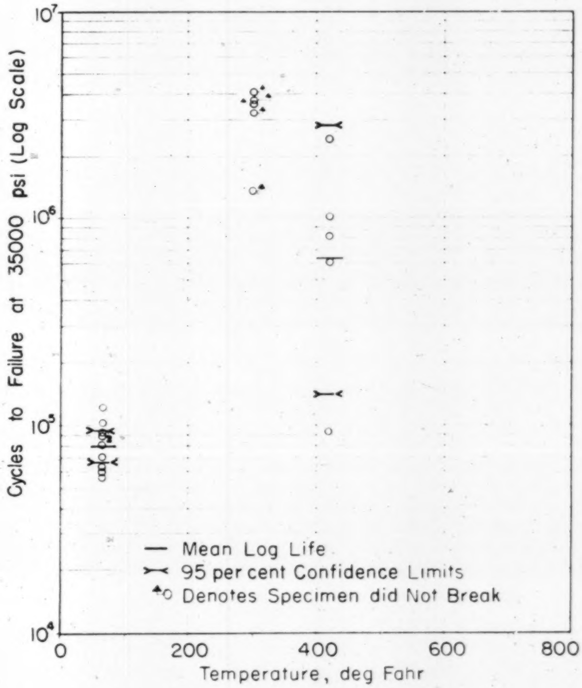


FIG. 12.—Test Results for Specimens with Nitrogen Restored (Wet Hydrogen Treated, Then Ammonia Treated).

Fatigue Results:

Fatigue data for each specimen are plotted in Figs. 10, 11, and 12 for batches Nos. I, II, and III, respectively. In these figures, the value of log $\bar{N}$ and the 95 per cent confidence limits for each set of results are also marked. These are denoted in each case by three short horizontal lines, the middle one representing the value of log $\bar{N}$, the other two the upper and lower confidence limits. The numerical values shown in Table I were computed according to the method previously outlined.

The Original Low-Carbon Steel (Batch No. I).—The confidence which may be placed in the apparent peak in fatigue life (Fig. 10) is readily assessed by means of the data presented in Table II. Comparing, in turn, the sets of lives at 220, 300, and 420 F with the set of lives at room temperature, Table II shows that there exists, in all cases, a 5 per cent level of significant difference between the means. This may be interpreted as indicating that there is only one chance in twenty that the lives of the specimens at any of the three elevated temperatures were drawn from the same population as the lives at room temperature. Comparing the actual life values, it may then be concluded that, for these four different temperatures, the shortest life occurred at room temperature.

TABLE I.—MEAN VALUES OF FATIGUE LIFE AND 95 PER CENT CONFIDENCE LIMITS.

Batch and Temperature	Log $\bar{N}$	$\bar{N}$ Cycles	Standard Deviation, σ	95 per cent Confidence Limits $\left(\log \bar{N} \pm \frac{t\sigma}{\sqrt{n}}\right)$			
				Upper		Lower	
				Log N_u	N_u	Log N_L	N_L
Batch No. I:							
Room temp.	4.89112	77 800	0.12067	4.97728	95 000	4.80496	63 800
220 F	5.12053	132 000	0.05477	5.15964	144 400	5.08142	120 600
300 F	5.22810	169 100	0.35050	5.47829	300 800	4.97791	95 000
420 F	5.90721	807 700	0.44586	6.22555	1 681 000	5.58887	388 100
530 F	5.24017	173 800	0.14217	5.34168	219 600	5.13866	137 600
700 F	4.58222	38 200	0.18097	4.66002	45 700	4.50442	32 000
Batch No. II:							
Room temp.	4.99682	99 300	0.09950	5.06786	116 900	4.92578	84 300
420 F	5.37248	235 700	0.18483	5.50445	319 500	5.24051	174 000
Batch No. III:							
Room temp.	4.90431	80 200	0.10954	4.98252	96 100	4.82610	67 000
300 F	...	...	...	...	...	...	...
420 F	5.81164	648 100	0.52187	6.46032	2 886 000	5.16296	145 500

TABLE II.—COMPARISON BETWEEN SAMPLE MEANS.

Comparison Between	$X_1 + X_2$	λ^2	λ	t	Level of Significant Difference
Batch No. I R.T.[a] and Batch No. I, 220 F	0.1813	0.01007	0.100	5.13	All less than 5 per cent
Batch No. I R.T. and Batch No. I, 300 F	1.2368	0.0687	0.262	2.98	
Batch No. I R.T. and Batch No. I, 420 F	1.9203	0.1067	0.327	6.95	
Batch No. I 420 F and Batch No. I, 220 F	1.8392	0.1022	0.320	5.99	
Batch No. I 420 F and Batch No. I, 300 F	2.8947	0.1608	0.410	3.84	
Batch No. I 420 F and Batch No. I, 530 F	4.9710	0.2984	0.546	2.73	
Batch No. I 420 F and Batch No. I, 700 F	2.0838	0.1037	0.322	9.20	
Batch No. II R.T. and Batch No. I, R.T.	0.2212	0.0112	0.106	2.28	
Batch No. II 420 F and Batch No. I, 420 F	2.0964	0.1166	0.342	3.49	
Batch No. II R.T. and Batch No. II, 420 F	0.3973	0.0221	0.148	5.66	
Batch No. III R.T. and Batch No. I, R.T.	0.2392	0.0122	0.111	0.27	>10 per cent

[a] R.T. = room temperature.

Again comparing, in turn, the lives at room temperature, 220 F, and 300 F with the lives at 420 F, it is found that, in all cases, a significant difference between means exists at the 5 per cent level. Hence it may further be concluded that, of the four sets of values, the mean life at 420 F was the greatest.

An important point here is that two specimens tested at 420 F did not break at more than 3 million cycles, but the calculations were carried out on the assumption that failure took place when the machine was stopped. Thus calculations involving the comparison between the mean life at 420 F and the mean life at some other temperature are bound to err on the conservative side, the true mean life at 420 F being greater than that shown in Fig. 10.

Turning now to the data at 530 and 700 F and comparing these sets of lives with that at 420 F, it is found that there is, in all cases, a significant difference between means at the 5 per cent level. Hence the life at 700 F was shorter than the life at 530 F which, in turn, was shorter than that at 420 F.

An attempt was made to estimate the exact value of the peaking temperature by drawing straight lines through the mean log lives in Fig. 10 at the various testing temperatures. It may be seen that the value of temperature corresponding to maximum life is approximately 460 F. If the error in temperature calibration of the specimen is estimated as ±25 F, the range 435 to 485 F is arrived at for the peaking temperature.

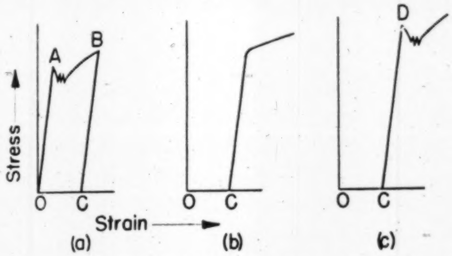


FIG. 13.—Strain Aging in Tension.

(*a*) Originally strained to *B* and unloaded to *C*. An upper yield point occurs at *A*.

(*b*) Curve obtained if immediately reloaded. No upper yield point.

(*c*) Curve obtained if reloaded after resting (at room or mildly elevated temperature). Upper yield point obtained at *D*.

This range of temperature may be compared with the predictions of the theoretical treatments developed in the Appendix. These are based on the hypothesis that the temperature at which maximum life occurs is determined by the rate at which dissolved carbon and nitrogen atoms segregate to dislocations in fatigue affected zones.

The first of the theoretical treatments (after Nabarro) assumes that the carbon and nitrogen atoms have to travel a distance of 2×10^{-6} cm during the aging process. Figure 15 shows $\log_{10} t^{-1}$ plotted against $\frac{1000}{T}$ where t is the time available for aging and T is the absolute (Kelvin) temperature. If t is equal to the time for a single load cycle to be applied, then at 2600 cycles per min the corresponding temperature in Fig. 15 is 500 F for both carbon and nitrogen. This temperature agrees well with the observed peak.

The second of the theoretical treatments (after Cottrell) considers the manner and path by which the interstitial atoms move in reaching dislocations. As shown in the Appendix, the maximum aging effect is forecast in the range 385 to 585 F when the diffusing atoms are nitrogen. Again this agrees well with the experimental peaking range of 435 to 485 F. With carbon as the diffusing atom, the predicted peaking range is considerably higher. This seeming discrepancy will be referred to later.

It may be well to emphasize that both explanations essentially describe different aspects of the same phenomenon. Cottrell's was developed from a fairly rigorous mathematical treatment but tells nothing directly about the size of domain involved. On the other hand, Nabarro's work suggests that the average interstitial atom moves a distance of the order of 2×10^{-6} cm but tells nothing about the distribution or availability of the interstitial atoms. It is interesting to note that the stated distance is very nearly that of the thickness of the individual lamellae of slip in aluminum observed by Heidenreich and Shockley (**14**). This size of domain also is comparable to the so-called "limiting fragment size" (**9**) or the closest approach between dislocations in a heavily cold worked zone. It appears then that the process of aging is one of diffusion to a dislocation from regions of linear dimension 2 × 10^{-6} cm, immediately adjacent to the dislocation.

Although much of the work on the deformation of metallic crystals has been established on the strength of electron microscope observations of aluminum, a structure of both fine and coarse slip lines has been observed in iron by Paxton, Adams, and Massalski (**10**). In common with aluminum, copper, lead, and gold, the formation of the slip lines was sensitive to the state of preparation of the surface. Whether the lamellae in iron are the same thickness as those in aluminum and are displaced by the same amount is not known. In any case, the validity of the diffusion calculations and of the strain-aging model is not critically dependent on the exact mode of slip within the crystal.

In comparing the theoretical predictions with the experimental results, there is another point to be noted. The theory predicts that, as temperature is increased, life will increase up to a maximum because of the larger number of dislocations being reanchored at the higher temperatures. It might be expected then that, when some maximum strength has been reached, the fatigue life would be constant over a certain range of temperature, since, if the interstitials have time to repin the dislocations at, say, 500 F, they have ample time to do so at 550 F. It will be observed in Fig. 10, however, that immediately after the peak was reached there was an extremely sharp drop in life. Two possible reasons suggest themselves for this decrease. The first is that, as soon as the maximum possible strengthening effect due to

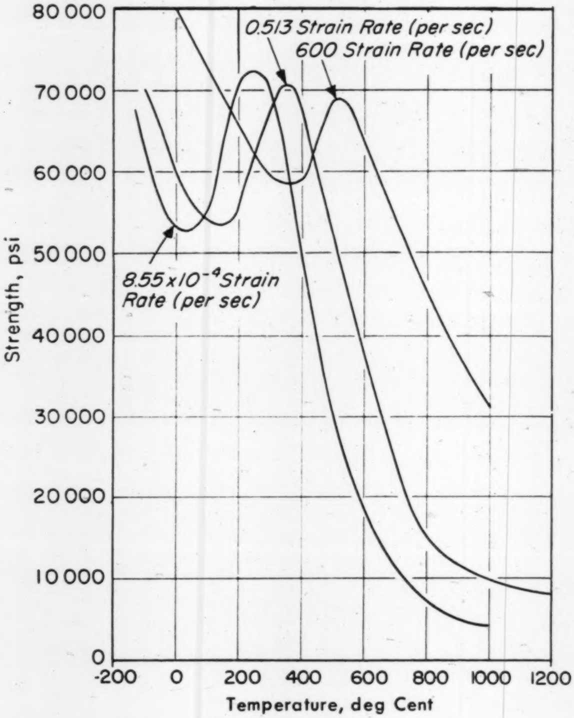


FIG. 14.—Effect of Temperature and Strain Rate on the Tensile Strength of Steel (**24**).

aging has been realized, the weakening indicated by the continuous drop in yield strength with increase in temperature begins to be evident. The second is that, when the peaking temperature is exceeded at a particular cyclic frequency, the interstitial atoms are able to move about so freely that they no longer exert a significant restraining influence on the movement of dislocations. This would be analogous to the sharp internal friction peaks observed in torsion pendulum experiments (11).

occurring at about the same temperature as did the peak for the original material.

The tension stress-strain curves of Figs. 8 and 9 show that a trace of yield point remained after the wet hydrogen treatment, so it is logical to expect that the strain-aging characteristics would not have been entirely removed. It is known from tension experiments that traces of strain aging are present even when carbon and nitrogen are removed below the limit of ordinary chemical analysis. As little as 0.001 per cent of these elements is sufficient to cause strain-aging tendencies.

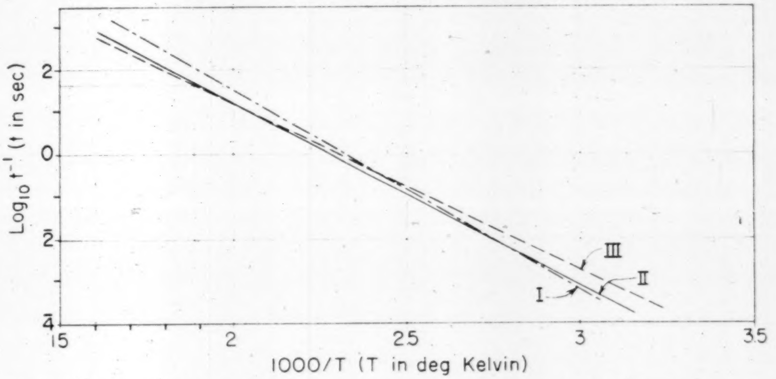


Fig. 15.—Relationship Between Temperature and Recovery Time of Yield Point in Low-Carbon Steel.

I—Muir's experimental results for time of recovery of yield point in mild steel. (After Nabarro.)
II—Representing the time taken for carbon atoms to travel 2×10^{-6} cm.
III—Representing the time taken for nitrogen atoms to travel 2×10^{-6} cm.

Specimens with Carbon and Nitrogen Greatly Reduced (Batch No. II).—The results of batch No. II specimens are presented in Fig. 11. Statistical analysis (Table II) shows that the mean life at 420 F was different from that at room temperature so that a peak life persisted in the material in the 400 to 500 F range. However, if the lives at 420 F are compared with the lives of batch No. 1 at the same temperature, it is found that these two sets of lives were also different at the 5 per cent level of significance. There was a less pronounced peak in the wet hydrogen treated batch,

To explore this avenue further, a few specimens were subjected to the wet hydrogen treatment in a glass tube furnace instead of in the steel pot that was previously employed. The aim was to secure a more thorough removal of carbon and nitrogen. Fatigue results for these half dozen specimens are denoted by triangles in Fig. 11. It will be seen that the peak is now absent, there being a continuous drop in life from room temperature up to 420 F. As carbon and nitrogen were removed from solution, there was a progressive decrease of the peaking tendency in fatigue life.

The Renitrided Specimens (Batch No. III).—These fatigue results are shown in Fig. 12 where it is seen that a strong peak in fatigue life was once more present, but in the region of 300 F compared with 460 F for the original material. There is little need to support this conclusion by statistical work. None of the five specimens that were run at 300 F broke, whereas those run at 420 F all had lives of less than 2½ million cycles. The room temperature performance for this material was very much the same as for the previous two batches, indicating that a true peaking phenomenon was observed and not merely an all-round increase in strength.

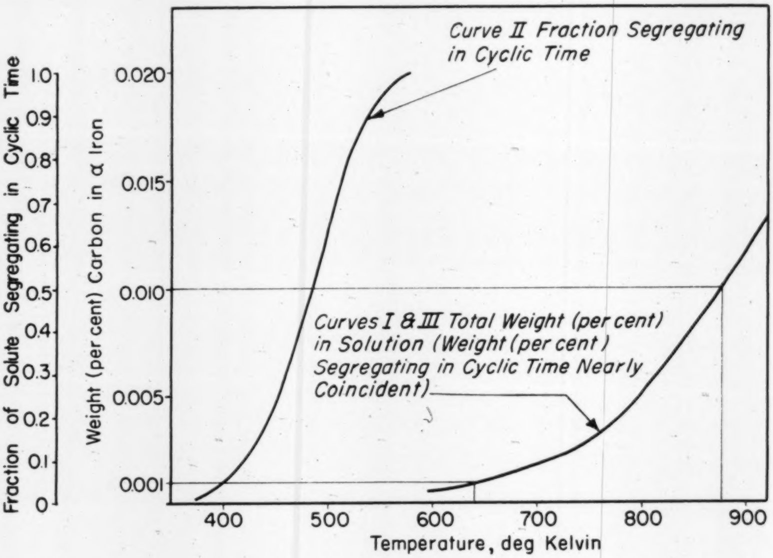


FIG. 16.—Segregation of Carbon to Dislocations During Strain Aging.

The strain-aging theory indicates that a peak should reoccur on the reintroduction of nitrogen, but the apparent shift in peaking temperature was an unexpected result. When it was observed, the calibration of the apparatus was checked but no adjustment was found to be necessary. Nabarro's work, as plotted in Fig. 15, leads to the expectation of nearly equal peaking temperatures for each of the two types of interstitial, especially at cyclic speeds in the region of 2600 rpm where the carbon and nitrogen lines run close together. The experimental result indicated, however, that when carbon and nitrogen were both present the peaking temperature was higher than when nitrogen alone was present.

Such a shift in peaking temperature might be accounted for by the existence of interaction between carbon and nitrogen atoms when both are present in the iron lattice. Wert (11), using internal friction measurements, has concluded that the rate of aging of one type of interstitial is influenced by the presence of the other. At 110 C he found that the presence of nitrogen caused carbon to precipitate two and a half times faster than it otherwise would. Again Fast (12) has found differences in behavior between iron containing nitrogen and iron containing carbon. For example, the Charpy impact value of technical iron shows a minimum at temperatures between 750 and 930 F, but there is no such minimum when carbon is the only impurity in the iron. With nitrogen as the impurity, there again is a minimum value in this temperature range. The difference in the critical temperature ranges for impact and fatigue might be accounted for by the higher rate of strain in the impact test.

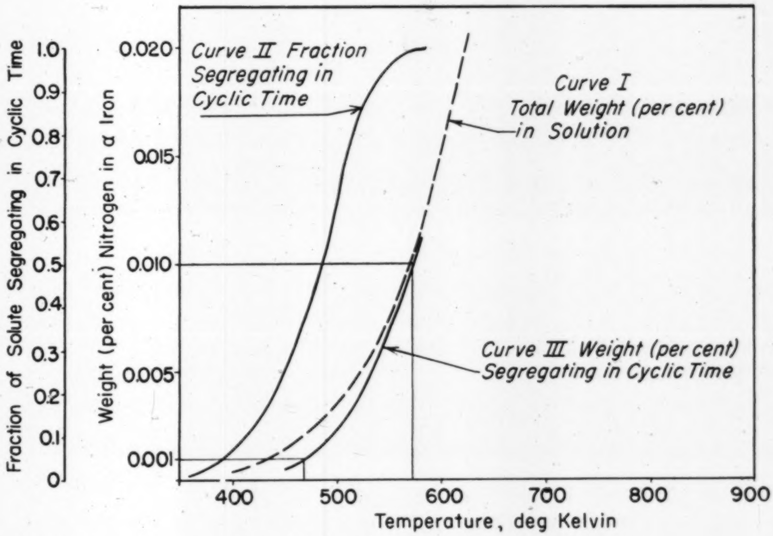


FIG. 17.—Segregation of Nitrogen to Dislocations During Strain Aging.

It is interesting that calculations, based on Cottrell's work, which are presented graphically in Figs. 16 and 17, predict a difference in peaking temperatures caused by nitrogen alone and carbon alone. Although nitrogen should cause a peak in fatigue life between 380 and 580 F, carbon should not cause a peak in life until the range 700 to 1000 F, a difference due mainly to the greater solubility of nitrogen at lower temperatures.

Possibly then the experimentally observed peak was in reality due to nitrogen, the effect being strengthened by the premature precipitation of carbon. More experimental work is needed to distinguish finally between the separate and combined aging effects of the two elements.

General Discussion:

The results suggest that mildly elevated operating temperatures are beneficial to fatigue resistance as far as low-carbon steel is concerned. The best operating temperature is, by the argument pursued in the Appendix, dependent on the frequency of the fatigue loading; in Fig. 18 are shown the theoretical temperatures for best performance at frequencies from 60,000 to 10 cycles per min. This curve is based on Eq 10 and so, in the light of the experimental results obtained, may give temperatures that are slightly too high. Also, at the higher temperatures, oxidation may become an important factor and there may be other changes in the metal that could prevent the formation of a relative peak.

It is noteworthy that, in general, as the mean fatigue life increases so does the scatter about the mean. This applies to each of the three different batches of material and is revealed by examination of the calculated values of standard deviation (Table I). Such a result is in agreement with previous observations on the width of scatter bands at different stress levels (7) in room temperature tests.

It is suggested that the variation in life observed in the present study may be interpreted in the following manner:

At constant stress amplitude, the relative scatter in life is a function of the number of microscopic zones in which fatigue cracks are nucleated. If a large number of cracks are nucleated, they may grow together and hence result in a short life for the specimen. Nucleation and growth of a small number of cracks should result in a longer life. Thus, to a first approximation, the life may be said to be inversely related to the number of cracks nucleated in the plane of final failure. Due to the inhomogeneous character of other than ideal materials, there will be different numbers of cracks formed, at the same nominal stress, in individual specimens of a given sample. This variation will be reflected in larger scatter in life when the mean number of cracks is small because the percentage variation in the number of cracks is greater. At slightly elevated temperatures, the strain-aging mechanism described in this paper has the

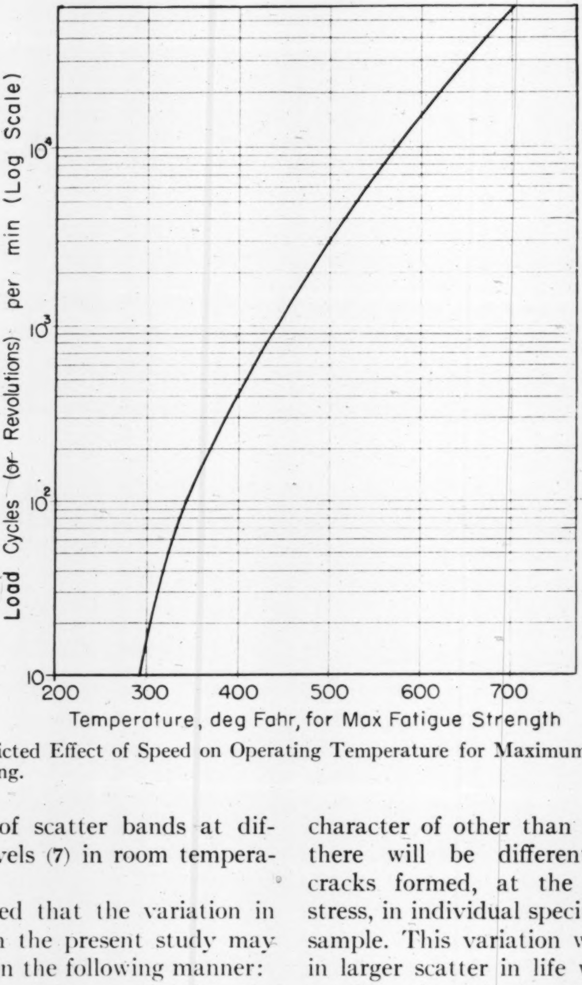


FIG. 18.—Predicted Effect of Speed on Operating Temperature for Maximum Fatigue Strength Due to Strain Aging.

effect of reducing the mean number of cracks nucleated at a given stress, thus resulting in increased fatigue life accompanied by increased scatter in life. This argument appears to be in line with the experimental results obtained.

Since some strain aging must occur even at room temperature during repeated loading, any picture of fatigue damage concerned with, let us say, low-carbon steel should take this into account as a contributory feature. For example, the coaxing phenomenon, for materials which strain age, is to be expected. During coaxing (**3**), a low stress is applied for a large number of cycles—that is, a long time—so that the affected zones are strengthened by aging. The stress is raised slightly and again a large number of cycles is run so that further strengthening of the same, or different, zones occurs. The fatigue resistance is thus gradually increased by a progressive strengthening of the weakest portions and the subsequent inhibition of crack nucleation and growth. Again the increase in strength which occurs during rest periods after the repeated loading of ingot iron (**13**) may be accounted for by the aging of fatigued portions.

In the final analysis, it must be kept in mind that all work in this report which has been characterized as "quantitative" might be more aptly described as "semi-quantitative," being based as it is on practical measurements of diffusion constants, solubility figures, and moduli of rigidity, in addition to the microscopically observed nature of crystal slip. Although a degree of success has been achieved in predicting the temperature at which peak fatigue life should occur for low-carbon steel, the direct theoretical problem of predicting the magnitude of this peak life is another, much more complex question. Nevertheless, in this investigation an attempt has been made to apply to an engineering problem theories originating in the field of metal physics. It is believed that such correlations of different fields of knowledge offer a fruitful approach to the understanding of fundamental engineering science.

CONCLUSIONS

The low-carbon steel used in the tests exhibited considerably greater fatigue life in the region of 400 to 500 F than it did at room temperature. Subsequent tests showed that the increase in life could be attributed to the presence of carbon and nitrogen in the metal. The effect could therefore logically be classified as one of strain aging which occurs during the course of the test.

Calculations, based on the assumption that the strengthening was caused by the diffusion of carbon and nitrogen atoms to dislocations which moved during local yielding, predicted the peaking temperature closely, provided that (*a*) the time available for aging to occur is of the order of the time to apply one load cycle, and (*b*) the distance the carbon and nitrogen atoms have to travel to achieve aging during the fatigue process is the same as the distance they travel under tensile conditions, namely 2×10^{-6} cm. (This also corresponds approximately to the "limiting fragment size" and to the closest approach of dislocations in a heavily cold-worked metal.)

Provided the theory, as developed, is substantially correct, it is to be expected that the peaking temperature depends on cyclic rate. It should range from about 300 F for a rate of 10 cycles per min up to about 700 F for 60,000 cycles per min. It appeared that when both nitrogen and carbon were present the peaking temperature was somewhat higher than when nitrogen alone was present. The reason for this is not clear, but it may be that there is an interaction between the two kinds of atoms when both are present. There is an indication in one aspect of the theory that a higher peaking temperature is to be expected for carbon than for nitrogen when they are separately present.

At higher values of mean life there was, in general, an increase in the scatter of the results.

Acknowledgment:

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APPENDIX

STRAIN AGING OF METALS

1. Dislocation Theory of Strain Aging:

At this time, the most satisfactory explanation of the occurrence of the upper yield point and of strain-aging effects is that based on Cottrell's theory (**25**). According to this theory, small interstitial atoms (for example, carbon and nitrogen in iron) tend to concentrate at the tensile side of dislocations in the crystal lattice since, in such positions, their energy is a minimum. From the mechanical point of view, more space exists between atoms at the tensile side of a dislocation; this enables solute atoms to fit in more easily, thus relieving the surrounding stress field. Once a particular solute atom occupies such a spot, energy barriers exist which make it difficult for a change of position to take place. This may be expressed by saying that there are forces of attraction between dislocations and the clouds of interstitial atoms.

Before slip can take place, the force between dislocations and nearby solute atoms must be overcome. However, once this has occurred, a smaller force is required to continue the movement of the freed dislocations which culminates in the slip process. Thus the theory gives a natural explanation of the two yield points encountered in strain-aging materials. The effect is greatest in those lattices in which the interstitial atoms cause an anisotropic strain, for example, in body-centered cubic systems such as α-iron.

If, after yield has taken place, the material is unloaded but the load immediately reapplied, yielding will continue at the same stress at which the test was interrupted since the interstitial atoms have had no time in which to diffuse to the new dislocation sites (see Fig. 13(*b*)).

If, however, the material is unloaded and allowed to rest for sufficient time to allow the interstitial atoms to diffuse and repin the dislocations, then upon reloading the two yield points will, once more, be in evidence (Fig. 13(*c*)).

Should the temperature during the rest period be raised, the carbon and nitrogen can diffuse more rapidly, and less time is required for the return of the yield points.

Cottrell's model also accounts for the different peaking temperatures shown in Fig. 14, since at faster rates of straining there is less time for aging to occur and therefore a higher temperature is required for the maximum effect. Evidently then, the time required to obtain the maximum strain-aging effect for given solute atoms in a given lattice depends upon the rate of diffusion (that is, upon the temperature) and upon the distance to be travelled by the solute atoms.

If the initiation and growth of fatigue

cracks are a consequence of the dynamic behavior of dislocations, it appears probable that strain aging will influence the fatigue behavior of metals as well as the tensile properties.

2. *Theories of Strain Aging Applied to Fatigue:*

(*a*) *Nabarro's Work.*—Nabarro (**27**) has carried out strain-aging calculations based on a movement of carbon atoms in α-iron, after tensile overstraining, of 2×10^{-6} cm and has shown good agreement with Muir's (**28**) experimental results on the time of recovery of yield point at various temperatures. However, values of diffusion coefficient and activation energy of carbon in iron were used which are not now the best available, and, in the following work, values due to Wert (**29**) are utilized. The effect of the movement of nitrogen will also be considered.

The diffusion coefficient, D, of a diffusion process is defined by the equation:

$$J = -D\frac{\partial c}{\partial x} \qquad (6)$$

where:

J = quantity in grams of the diffusing substance which passes per unit time through unit area of a plane at right angles to the direction of diffusion,

c = concentration of the diffusing substance per unit volume, g per cu cm,

x = ordinate coinciding with the direction in which diffusion occurs, and

D = diffusion coefficient, sq cm per sec.

By a process of diffusion of interstitial atoms to dislocations, the order of the time t (in seconds) to achieve equilibrium in a pattern of linear dimensions x (centimeters) has been given by Nabarro (**27**) as:

$$t = \frac{x^2}{2D} \qquad (7)$$

In conjunction with Eq 7, another diffusion relationship may be used which gives the coefficient at any temperature in terms of the coefficient at infinite temperature:

$$D = D_0 e^{-\Delta H/RT} \qquad (8)$$

where:

D_0 = diffusion coefficient at infinite temperature, sq cm per sec,

ΔH = activation energy for the process, cal per mol,

R = universal gas constant (= 1.986 cal per deg Cent per mol, and

T = absolute temperature (deg Kelvin).

Substituting from Eq 8 into Eq 7:

$$t^{-1} = \frac{2D}{x^2} = 2D_0 x^{-2} e^{-\Delta H/RT} \qquad (9)$$

or:

$$\log_{10} t^{-1} = \log_{10} (2D_0 x^{-2}) - \frac{\Delta H}{RT} \log_{10} \text{e.} \qquad (10)$$

and for a particular x, ΔH, and D_0:

$$\log_{10} t^{-1} = C_1 - \frac{C_2}{T} \qquad (11)$$

where C_1 and C_2 are constants. It follows that a plot of $\log_{10} t^{-1}$ against $1/T$ should be a straight line.

For evaluation of Eq 10, the following values of the constants due to Wert (**29**) have been used:

For carbon in α-iron, $\Delta H = 20{,}100$ cal per mol. $D_0 = 0.02$ sq cm per sec.

For nitrogen in α-iron, $\Delta H = 18{,}200$ cal per mol. $D_0 = 0.003$ sq cm per sec.

The value of $x = 2 \times 10^{-6}$ cm has been retained and, when these figures are substituted in Eq 10, the following are obtained:

$$\text{For carbon, } \log_{10} t^{-1} = 10.00 - \frac{4400}{T} \qquad (12)$$

$$\text{For nitrogen, } \log_{10} t^{-1} = 9.18 - \frac{4000}{T} \qquad (13)$$

These equations are plotted as curves Nos. II and III in Fig. 15 with $\log_{10} t^{-1}$ as ordinate and $1000/T$ as abscissa. For comparison, Muir's experimental results, as interpreted by Nabarro (**27**), are shown in the same figure and constitute curve No. I.

It is seen that the three lines in Fig. 15 lie close together in the range of temperature examined and that the shorter the time the higher the temperature must be for effective aging to occur.

If Fig. 15 is now applied to conditions of repeated load and if it is assumed that the time t available for aging is the time of one loading cycle, then from curves Nos. II and III, the corresponding value of $1000/T$ may be read off. This value of T will be the temperature at which the material should have a maximum life at the specified loading frequency for stresses above the endurance limit.

Since the machine speed of 2600 rpm represents a cyclic time of 60/2600 sec, the value of $\log_{10} t^{-1}$ is then 1.637; from Fig. 15, the corresponding value of $1000/T$ is 1.89 for both carbon and nitrogen. This gives a value of T of 530 K or 500 F, the temperature at which low-carbon steel should exhibit a maximum fatigue strength when the cyclic rate is 2600 rpm.

(*b*) *Cottrell's Strain-Aging Theory.*—The analysis based on Nabarro's method assumes that the interstitial atoms have to move a certain distance, namely 2×10^{-6} cm, in order to achieve pinning. The theory does not consider the exact paths travelled by the atoms nor does it predict the number of atoms, or the fraction of the total solute, arriving at dislocations in a given time at a given temperature.

Later work by Cottrell and others (**25, 26, 30, 31, 32, 33**) provides such information and may be used as a somewhat different approach to estimate the temperature at which maximum fatigue life may be expected.

Figures 16 and 17 present the results of calculations made to determine the temperatures at which 10^{-2} and 10^{-3} weight per cent of the solute atom will segregate in the time corresponding to one loading cycle. Details of the calculations are given in the original report (**34**). In both figures curve No. I represents Dijkstra's (**33**) results for solubility of carbon or nitrogen at the corresponding temperatures. Curve No. II gives the relationship between the fraction of solute segregating in cyclic time and the temperature T; curve No. III is the product of curves Nos. I and II and therefore represents the weight per cent of solute atom which can segregate in cyclic time.

In curve No. III of Fig. 16, the temperatures corresponding to segregated weight per cents of 10^{-3} and 10^{-2} of carbon are 640 and 875 K, respectively. These temperatures correspond to 693 and 1113 F.

In curve No. III of Fig. 17, the temperatures corresponding to segregated weight per cents of 10^{-3} and 10^{-2} of nitrogen are 467 and 575 K, respectively, corresponding to 380 and 575 F.

It follows that, according to this procedure, peak life should occur in the range 693 to 1113 F for iron containing carbon and in the range 380 to 575 F for iron containing nitrogen. If both carbon and nitrogen are present, a peak in the life *versus* temperatures curve would be expected in both ranges of temperature unless there is some type of interaction between the two kinds of interstitial atoms.

To summarize the theoretical findings, both procedures indicate that a peak in the fatigue life, due to strain aging, should occur in the region of 500 F when the cyclic rate is 2600 rpm. A curve, calculated from Eq 10, giving the predicted temperatures for maximum fatigue strength for a range of cyclic rates of loading, is shown in Fig. 18.

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DISCUSSION

Mr. H. E. Lardge.[1]—I notice that the strain-aging effects and the change in fatigue value for mild steel were most marked around 420 F. Has it anything to do with the brittle range of mild steel?

Mr. G. M. Sinclair (*author*).—Yes, basically the same mechanism is responsible. We may consider the "blue brittle" range as one more strain-aging effect. This range, however, is determined by an interrelation between strain rate and temperature. In the case of fatigue, we have attempted to express this temperature, at which a strength maximum is observed, as a function of testing frequency.

Mr. C. R. Smith.[2]—I noticed some time ago there seemed to be the same effect on static strength of mild carbon steels. Take ordinary 1025 steel, which has tensile strength about 65,000 psi. If I remember right, it will run as high as 75,000 or 80,000 psi between 400 and 500 F. The yield strength had more or less the same sort of a characteristic. Do you think that this might have something to do with it? This is just static strength.

Mr. Sinclair.—Yes, the effects in "static" tension and in fatigue are directly related. Once again, the same explanation may be applied. The temperature at which this maximum is obtained will vary, depending upon the strain rate at which the tests were conducted.

If the test is conducted at an increased strain rate, this "peak" in tensile strength will shift in a direction of higher temperature.

Mr. P. R. Toolin.[3]—Perhaps it is of interest to note that a similar phenomenon occurs in some of the superalloys at somewhat higher temperatures. For example, the fatigue strength *versus* temperature relationship of "Refractaloy-26" has a maximum at about 1100 F.[3a] While the tensile strength, at a strain rate of about 5 per hour, in the 1100 F region does not exceed that at room temperature, the 1050 F stress-strain diagram shows the most severe aging serrations encountered over the room temperature to 1600 F range.

Mr. Sinclair.—I believe that the increase in fatigue limit of the alloy in the temperature range mentioned was likely due to a precipitation hardening effect rather than pinning of dislocations by some interstitial atom. As precipitate particles can act as "roadblocks" to dislocations, the effect on strength properties would be somewhat similar.

In general, any metallurgical change which results in interference with the motion of dislocations would be expected to increase the tensile strength, the yield strength and the fatigue strength of a metal.

Mr. K. Winterton.[4]—Will the author agree that provided the fatigue cycling was carried out at sufficiently slow speed, the maximum strength would be shifted to room temperature. I think it depends entirely upon the mobility of these atoms at the test temperature.

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[3] Mechanics Department, Westinghouse Research Laboratory, East Pittsburgh, Pa.

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[4] Assistant Director, Department of Engineering and Metallurgy, Ontario Research Foundation, Toronto, Canada.

For example, I have seen similar cases in the static properties of iron and molybdenum, where the hydrogen atom, which is considerably more mobile, appears to affect the properties at ambient temperature.

Tests by H. G. Vaughan at the British Welding Research Assn. (private communication) have shown that after slightly straining a steel specimen to remove the sharp yield point, a new yield phenomenon can be produced at room temperature by the introduction of hydrogen by electrolysis. The effect disappears as the hydrogen is lost by diffusion.

MR. SINCLAIR.—Yes, I agree, the theory certainly would lead us to believe that if we were to lower the frequency to a sufficiently low value that the peak could be obtained at room temperature. We based our calculated curve on the diffusion of carbon and it turns out that for a cyclic frequency of about 10 cpm, which is quite low, the optimum temperature would still be about 300 F. Nitrogen is able to diffuse a little more rapidly; therefore the optimum temperature for nitrogen rather than carbon may be closer to room temperature.

MR. HENRY E. FRANKEL.[5]—If one removed carbon or nitrogen, both elements having atomic radii smaller than iron, and therefore removing any future roadblocks for the dissipation of dislocations through the lattice why would not hydrogen do the same thing?

MR. SINCLAIR.—The reason that hydrogen is not very effective at room temperature or at these elevated temperatures, is that in iron it diffuses very rapidly. The heat of activation for diffusion of hydrogen in iron is roughly one fifth of that for nitrogen in iron. This is very low. In order to attain a peak with hydrogen as a pinning atom, we would have to conduct our tests at subzero temperatures, say, 100 to 200 C.

It may be that the low temperature embrittlement effect (transition temperature) which is observed in iron, molybdenum, tungsten, chromium, and so on is caused by the pinning of dislocations by some interstitial impurity such as hydrogen, which becomes effective at very low temperatures.

MR. R. E. PETERSON[6] (*presented in written form*).—Mention is made of the average interstitial atomic movement of 2×10^{-6} cm as being in approximate agreement with the thickness of slip lamellae observed by Heidenreich and Schockley (lamellae were 200 Å thick with steps of 2000 Å). Since their work was carried out with 99.99 per cent pure aluminum this must mean that very small amounts of impurities are sufficient for determining slip behavior throughout the specimen. One reason for my raising this point is that Forsyth (Farnborough) has found the slip extrusion effect (which depends on movement of interstitial atoms) in age hardenable aluminum alloys but not in "pure" aluminum.

MR. A. B. WILDER[7] (*presented in written form*).—The paper presented is of particular interest because of its application to Cottrell's dislocation theory of strain aging. It would be helpful to know the carbon, oxygen, and nitrogen contents of all the materials tested. Also, the aluminum-nitride content may be significant.

According to Cottrell's theory, as discussed by the authors, carbon and nitrogen tend to concentrate in lattice dislocations with less time required at certain peak temperatures. Also, with regard to the phenomenon of coaxing, the authors have pointed out that aging is to be expected in that a low stress is applied for a long time (great number of cycles) and then the stress is raised and again applied for a long time. The fatigue strength is thus gradually increased by inhibition of crack nucleation and growth. The practical implications of these observations are significant and any comments by the authors on this aspect of the problem will be of interest.

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[6] Mechanics Department, Westinghouse Research Laboratory, East Pittsburgh, Pa.

[7] Chief Metallurgist, National Tube Division, U. S. Steel Corp., Pittsburgh, Pa.

A study of strain aging in fatigue with commercial alloys containing different levels of nitrogen combined with iron, aluminum, and possibly chromium, may provide information of practical significance. Results with notched-fatigue and corrosion-fatigue specimens would also enlarge our knowledge of this interesting field of fatigue research. Recently G. Lagenberg[8] and A. Josefsson have discussed the influence of grain boundaries on the behavior of carbon and nitrogen with regard to internal friction (damping) and have demonstrated that grain size influences the internal friction due to either carbon or nitrogen. This suggests that grain size may be a factor which should be considered in evaluating strain aging in fatigue.

MESSRS. J. C. LEVY AND G. M. SINCLAIR (*authors' closure*).—As Mr. Peterson suggests, earlier work on the problem of strain aging indicates that very small amounts of impurities may have a considerable effect on the subsequent slip behavior of a metal. For example, as little as 0.001 per cent by weight of nitrogen in iron can influence the yield point behavior.

Mr. Wilder's comments relating to the chemical analysis of the materials used are quite true. Unfortunately, the special facilities needed to determine carbon and nitrogen contents of steel accurately in the range of 0.01 and 0.001 per cent by weight were not available at the time this work was done and we had to report details of heat treatment and microscopic examination instead. As Mr Wilder points out, future possibilities for the investigation of strain aging effects in fatigue appear quite interesting and in some instances may be found to have a practical application. Some exploratory work on the relationship between strain aging and the coaxing effect in fatigue was reported in an earlier paper.[9]

The authors wish to thank the discussors of this paper for their interest and for their contributions in bringing out additional information on the subject.

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UNDERSTRESSING AS A MEANS OF ELIMINATING THE DAMAGING EFFECT OF FATIGUE STRESSING*

By H. E. Frankel[1] and J. A. Bennett[1]

Synopsis

Rotating-beam tests of a heat-treated alloy steel showed that the fatigue limit could be increased by coaxing. The damaging effect of fatigue stressing 10 per cent above the fatigue limit was eliminated by understressing and coaxing. Damage produced by a stress 30 per cent above the fatigue limit was not completely eliminated. Specimens coated with a rust-preventive oil showed greater fatigue resistance than clean specimens.

When a metal is subjected to a fluctuating stress of sufficient magnitude, progressive damage occurs which culminates in the formation of a fatigue crack. As there is no known non-destructive method for detecting fatigue damage prior to the start of an actual crack, many structural parts are replaced after a certain length of service because of the danger of fatigue failure.

It is well known that the fatigue strength of metals can be considerably improved by a variety of mechanical treatments such as shot peening (**1**)[2] and surface rolling (**2**), which work-harden the surface and produce in it a compressive stress. Understressing, that is, applying a large number of cycles of stress below the fatigue limit, has also been shown to increase both the fatigue limit and the fatigue life of ferrous metals (**3**). However, there has been relatively little investigation of the effect of such treatments on specimens which have been damaged by stressing above the fatigue limit. Moore (**4**) and Bennett (**5**) show results on individual specimens which indicate that understressing can eliminate the effect of prior overstressing, but all of these tests were made on annealed or normalized steels. No data of this type for quenched-and-tempered steels have come to the authors' attention.

If the damaging effect of stressing above the fatigue limit can be eliminated by suitable treatment, it would be of considerable practical importance and would also provide information that would further our understanding of the mechanism of fatigue fracture. An investigation of possible methods of eliminating fatigue damage is now in progress. This report presents the results of the first phase of the investigation.

The symbols and terminology used in this report are in accordance with the definitions in the ASTM Manual on Fatigue Testing (**6**).

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* Presented at the Fifty-eighth Annual Meeting of the Society, June 26–July 1, 1955.

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[2] The boldface numbers in parentheses refer to the list of references appended to this paper, see p. 899.

MATERIALS AND TESTING PROCEDURE

All of the tests were conducted on R. R. Moore rotating-beam fatigue testing machines operated at speeds of 6000 to 9000 rpm. The reduced sections of the specimens had a 4-in. contour radius and a minimum diameter of 0.25 in. They were prepared from SAE 4340 steel having the following composition (per cent by weight):

Carbon, per cent	0.40
Manganese, per cent	0.66
Phosphorus, per cent	0.014
Sulfur, per cent	0.025
Silicon, per cent	0.29
Nickel, per cent	1.74
Chromium, per cent	0.77
Molybdenum, per cent	0.23

The rough machined specimens were heat treated by holding at 1500 F for 30 min, quenching in oil, and then double tempering at 1100 F for 1 hr each time. This resulted in a structure of tempered martensite with the following mechanical properties:

Hardness Rockwell C	32 to 34
Tensile strength, psi	156 900
Yield strength, 0.2 per cent offset, psi	147 000
Reduction of area, per cent	60.0

After heat treatment the specimens were ground with an 8-in. diameter wheel (alundum 32-60G12V), the plane of which was parallel to the length of the specimen. This operation was carefully controlled to avoid overheating the surface; the final cuts were very shallow. The preparation of the specimens was completed by polishing in a longitudinal direction with 1 G paper followed by 400 Aloxite paper. These operations were carried out on the automatic polishing machine described earlier (7) which operates at low speed with a small constant pressure between the specimen and abrasive. Although this procedure does not produce a highly polished surface, the surface condition is reproducible from specimen to specimen. Except for a few of the early specimens, all specimens were coated with a rust-preventive oil immediately after polishing. The majority of experiments were run with specimens that had been cleaned with a solvent just prior to testing, but a number of tests performed on specimens that had not been cleaned gave results different from those on the clean specimens.

TABLE I.—RESULTS OF FATIGUE TESTS AT CONSTANT STRESS AMPLITUDE.

Stress Amplitude, psi	Number of Specimens	Per cent Fractured	Cycles to Fracture			
			$\overline{\log N}$	σ_u	Antilog $\overline{\log N}$	Median
85 000	3	0				
86 000	30	10				
87 000	9	78				314 × 10^3
88 000	11	73				280
90 000	10	90	5.375[a]	0.329[a]	237 × 10^3[a]	210
95 000	9	100	5.262	0.235	183	181
100 000	5	100	4.926	0.087	84	79
105 000	5	100	4.792	0.149	62	59
115 000	10	100	4.440	0.113	27.6	29.5

[a] These values are based on the results of the nine specimens which fractured and are therefore smaller than the true values.

RESULTS AND DISCUSSION

The results obtained in tests at constant stress amplitude are presented in Table I and Fig. 1. The "fatigue life" line is based upon the median values rather than the mean as the latter would necessarily be infinite at stress levels where some specimens do not fail. As the stress approached the fatigue limit, the "unbiased" standard deviation, σ_u, of the fatigue life N, increased.

The data obtained at stresses near the fatigue limit are shown in a normal probability graph, Fig. 2. It is apparent from Table I that the value at 86,000 psi is the most precise due to the large number of specimens tested at this level; accordingly, the line was drawn through this point. From this line it was determined that the mean fatigue limit was 87,400 psi, and the standard deviation 1100 psi. The dashed lines in Fig. 1 show the approximate range of ±σ from the central relationship for both the finite portion of the S-N curve and for the fatigue limit. Comparison of the vertical spread of these lines indicates that the fatigue limit shows less dispersion than the stress to cause fracture in a finite number of cycles.

Figure 3 shows the effect of an oil film on the fatigue strength of the steel. The curve for the oiled condition is based on only nine specimens and the difference might not be considered significant, but similar differences were found in the other tests reported below.

The term "coaxing" has been used to describe the application of a large number of cycles at each of a series of stresses of increasing amplitude. This treatment has been shown (8) to result in large increases of fatigue limit for some

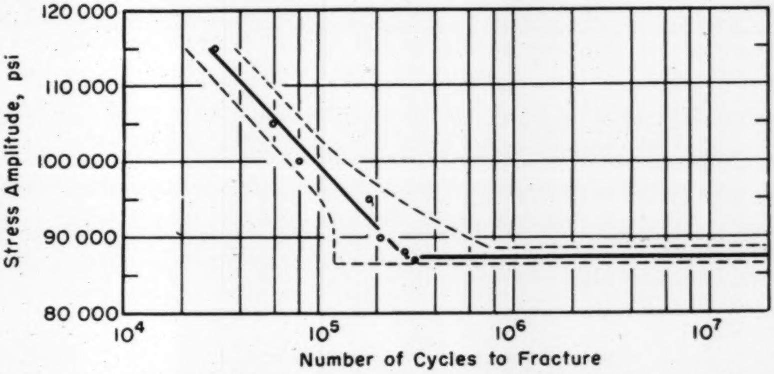

FIG. 1.—Basic S-N Curve for Quenched and Tempered SAE 4340 Steel Used in the Investigation. The points shown are median values. The dashed lines represent approximate limits of plus and minus one standard deviation from the central value.

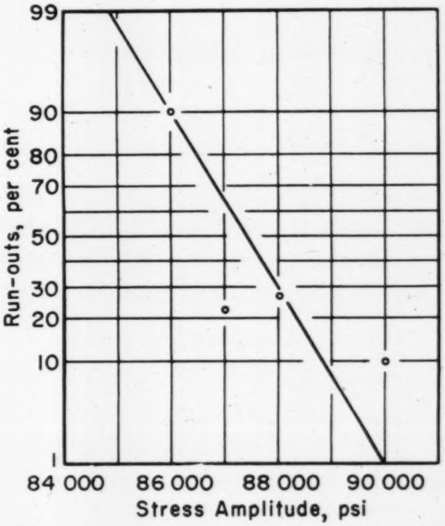

FIG. 2.—Per Cent of Run-Outs as a Function of Stress Amplitude. (Tests were stopped at 20 × 10^6 cycles.)

materials. Accordingly, the major part of the effort in this phase of the investigation was directed to a study of the effect of coaxing on both damaged and undamaged specimens.

Specimens were coaxed from two stress levels, 80,000 and 86,000 psi, to determine if the initial stress had any effect on the effectiveness of the coaxing procedure. Figure 4 shows the results obtained, plotted as the per cent run-outs *versus* the stress level.[3] The basic data for both clean and oiled specimens are shown for comparison, but it should be noted that the data are not exactly similar because of the cumulative nature of the coaxing test results. It is apparent that coaxing, beginning at either of these stresses, raised the fatigue limit, and that greater improvement was obtained when the initial stress was close to the fatigue limit. The increase in fatigue limit was smaller than that which has been reported for softer steels.

Kommers (4), Sinclair (8), and others have reported that the size of the stress increments has an effect upon the highest fatigue limit value attained by coaxing.

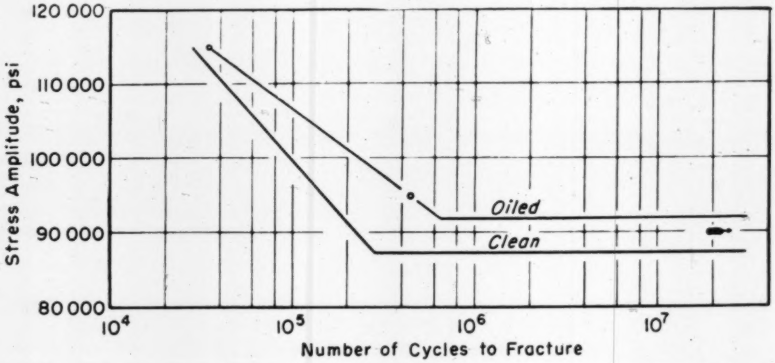

FIG. 3.—Comparison of Fatigue Properties of Oiled and Clean Specimens. Open circles represent median values.

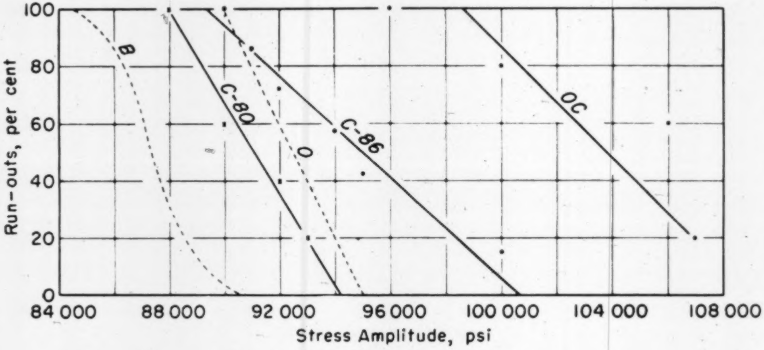

FIG. 4.—Results of Coaxing Tests.

B—Basic curve from Fig. 2.
O—Basic curve for oiled specimens.
C-80—Clean specimens coaxed with an initial stress of 80,000 psi.
C-86—Clean specimens coaxed with an initial stress of 86,000 psi.
OC—Oiled specimens, coaxed with an initial stress of 86,000 psi.

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[3] In Figs. 4 to 9 each point plotted represents an individual test result.

The results shown in Fig. 5 indicate an increase in improvement with decreased step size, the same trend found by the previous investigators. As the total increase is small, some of the apparent effect of step size may be due to the greater chance of applying a stress close to the new fatigue limit when the increments are small. In order to obtain the maximum benefit, all the tests described below which involved coaxing were conducted with increments of 1000 or 2000 psi. In coaxing tests, the fatigue limit reported is the highest stress at which the specimen ran 20 × 10^6 cycles or more.

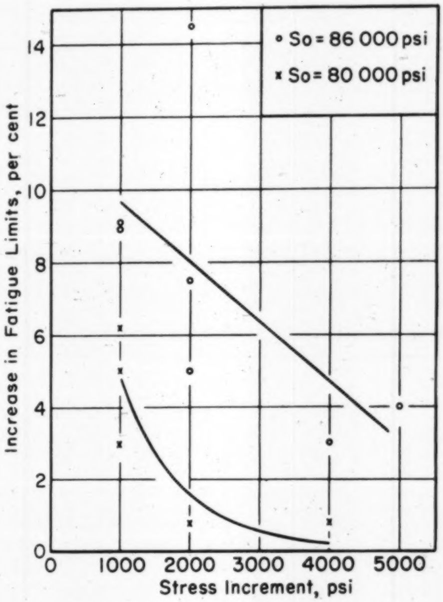

FIG. 5.—Effect of Stress Increment on Improvement Due to Coaxing. S_o = initial stress used in coaxing.

The effect of coaxing on damaged specimens was evaluated by overstressing at 115,000 and 95,000 psi. Figure 6 shows the basic fatigue data, plotted on a cumulative probability basis, for stress levels of 95,000 and 115,000 psi. The points labeled N_f indicate the number of cycles for fracture; N_c indicates the approximate number of cycles at which the first fatigue crack developed. These latter values were obtained by stopping the tests at intervals, measuring the cracks, and extrapolating the crack growth curves back to a length of 1 per cent of the circumference.

The number of cycles of stress to be applied was determined as the intersection of the N_c curve with the 10 per cent line of Fig. 6. These values and the corresponding cycle ratios were:

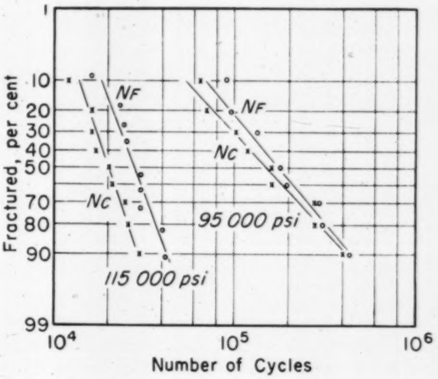

FIG. 6.—Probability of Fracture as a Function of Number of Cycles.

N_c—Number of cycles to start of cracking.
N_f—Number of cycles to fracture.

	95,000 psi	115,000 psi
Number of cycles for 10 per cent probability of cracking........	55 000	14 000
Cycle ratio, based on mean N_c.....	36 per cent	70 per cent
Cycle ratio, based on mean N_f.....	31 per cent	50 per cent

It is of course recognized that the degree of damage does not necessarily bear any simple relation to the cycle ratio.

Overstressing was following by reducing the stress to 80,000 psi and coaxing at progressively higher stresses until failure occurred. The results, shown in Fig. 7, indicate that in some cases the fatigue limit of specimens overstressed at 95,000 psi was not only restored but even improved somewhat by coaxing. However, specimens which had been damaged at 115,000 psi could not be coaxed above the original fatigue limit.

As shown in Fig. 8, specimens which were damaged then oiled and coaxed showed consistent improvement above the basic properties, although they did not reach the values for undamaged specimens which were similarly treated. One group of specimens was damaged at 95,000 psi, then coaxed from an initial stress of 90,000 psi; some of these reached much higher fatigue limits than those coaxed from lower stress levels. In all tests of oiled specimens where long runs were involved, the surface was oiled almost every day to make sure that the film was maintained.

In order to determine the efficacy of a single understress treatment, as compared to the stepwise coaxing procedure, a group of specimens was subjected to a stress amplitude of 86,000 psi for more than 20 × 10^6 cycles and then run to failure at a higher stress. The results plotted in Fig. 9 show some increase in both the mean and the dispersion as a result of the understressing treatment. However, analysis by the null hypothesis indicates that the difference of the means is not significant at the 90 per cent confidence level.

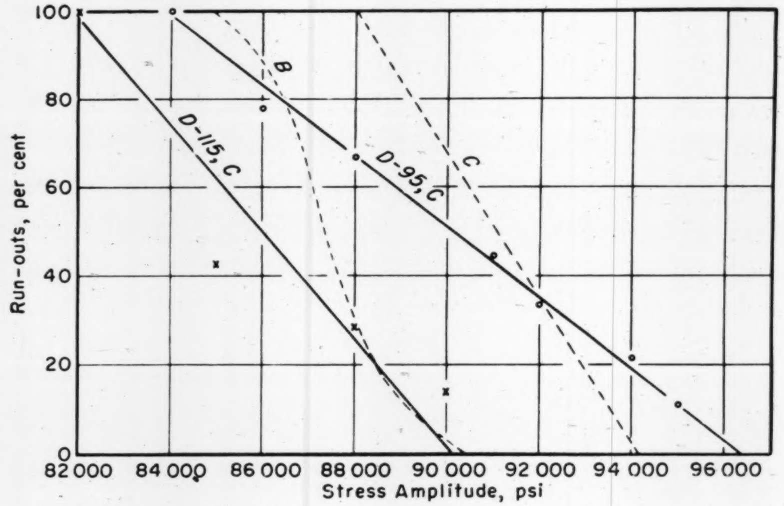

FIG. 7.—Effect of Coaxing on Cleaned, Damaged Specimens.

B—Basic curve from Fig. 2.
C—Coaxed, S_o = 80,000 psi (Fig. 4).
D-95, *C*—Damaged at 95,000 psi, coaxed from 80,000 psi.
D-115, *C*—Damaged at 115,000 psi, coaxed from 80,000 psi.

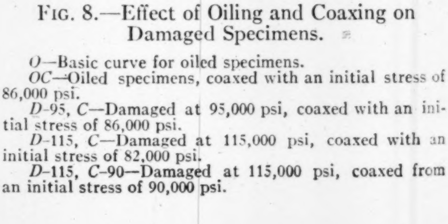

FIG. 8.—Effect of Oiling and Coaxing on Damaged Specimens.

O—Basic curve for oiled specimens.
OC—Oiled specimens, coaxed with an initial stress of 86,000 psi.
D-95, *C*—Damaged at 95,000 psi, coaxed with an initial stress of 86,000 psi.
D-115, *C*—Damaged at 115,000 psi, coaxed with an initial stress of 82,000 psi.
D-115, *C*-90—Damaged at 115,000 psi, coaxed from an initial stress of 90,000 psi.

To determine the effect of overstressing on the fatigue life, a group of specimens was overstressed for 31 per cent cycle ratio at 95,000 psi, then tested at 90,000 psi. The median value of N_f for these specimens was only 5 per cent below that for the basic material, and one specimen out of seven ran out. The overstressing treatment did not, apparently, cause a significant amount of damage as measured at a lower stress.

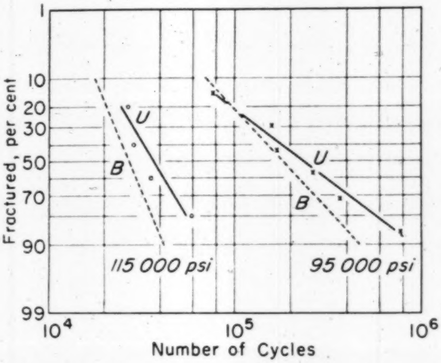

FIG. 9.—Effect of Understressing on Fatigue Life at 95,000 and 115,000 psi.

B—Basic curves, from Fig. 6.
U—Understressed specimens.

The tests on understressing of damaged specimens had indicated that this small amount of damage could be repaired. In order to verify this, a cleaned specimen was overstressed for 55,000 cycles at 95,000 psi, then understressed at 86,000 psi for more than 20×10^6 cycles. This procedure was repeated 25 times, corresponding to a cumulative cycle ratio of 7.6 at 95,000 psi, and the specimen remained unbroken. Figures 2 and 6 show that the chance of a specimen running this many cycles in a constant amplitude test is extremely small. This indicates clearly that the damage due to overstress was repaired by understressing. After the completion of the last 55,000 cycles at 95,000 psi, the test was continued and the specimen fractured after an additional 143,000 cycles. This is within the normal scatter range for this stress level, indicating that the understressing eliminated the damage due to overstress but did not improve the basic properties as coaxing would have.

Similar tests in which the overstressing was carried out at 115,000 psi resulted in no significant increase in cumulative cycle ratio, regardless of the cycle ratio (25 to 65 per cent) used in overstressing or the stress level (75,000 to 82,000 psi) used for understressing.

The interesting fact that the oil used in these tests raised the fatigue limit and increased the fatigue life of both the damaged and undamaged specimens is difficult to explain. The possibility that the effects were due to the prevention of corrosion does not appear probable because: 1. The difference was apparent in tests lasting only 5 to 20 min. 2. The majority of tests were conducted in the winter, when the humidity in the laboratory was low. 3. Specimens cleaned of oil immediately before a test gave apparently the same results as those which had never been oiled.

To investigate the possibility of chemical action, a group of disks cut from tested specimens were carefully cleaned and weighed, then placed in the oil. Reweighing after intervals up to several weeks indicated no significant weight change. The mechanism of the effect of the oil is, therefore, still open to question.

Sinclair (8) recently reported studies of the coaxing effect in fatigue which led him to the conclusion that strain-aging was the mechanism primarily responsible for the effect. The tempered martensitic material used in the current investigation would not be expected to strain-age to an appreciable extent. This was verified by plastically deforming a specimen in static tension, heating it 1 hr at 100 C, and again loading it in tension. The stress-strain curves for this specimen, Fig. 10, show the absence of any strain-aging effect. As strain-aging is time-dependent, the improvement in fatigue limit would be expected to be greater when the understressing procedure was started at 80,000 psi than when it was started at 86,000 psi. Just the reverse was found experimentally. It appears that strain-aging was not a factor in the improved fatigue limit due to coaxing in this material.

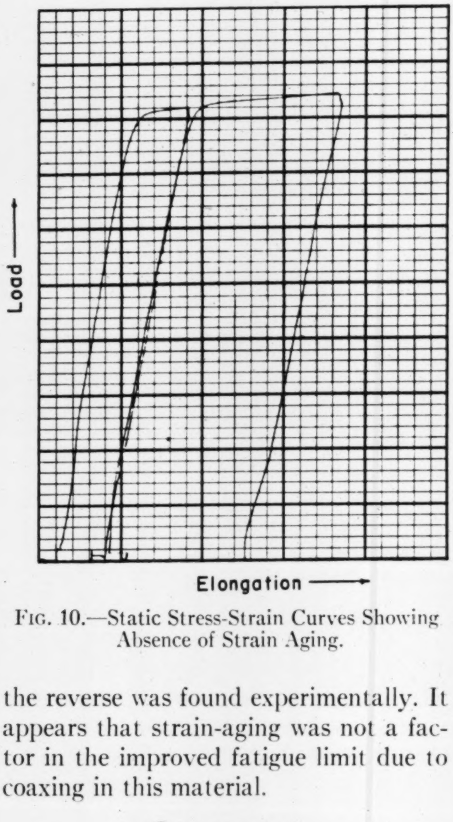

FIG. 10.—Static Stress-Strain Curves Showing Absence of Strain Aging.

CONCLUSIONS

The following conclusions apear to be warranted from the results of fatigue studies on quenched-and-tempered SAE 4340 steel reported above.

1. In tests conducted at constant stress amplitude, the standard deviation of the number of cycles to fracture increased as the stress amplitude approached the fatigue limit.

2. The dispersion of the fatigue limit, however, was smaller than the dispersion in the stress amplitude required to cause fracture in a finite number of cycles.

3. Specimens which were kept coated with a rust-preventive oil during the test showed greater fatigue resistance than oil-free specimens.

4. The fatigue limit was raised in all cases by a coaxing procedure. The improvement was greater for tests in which the initial stress was close to the fatigue limit than for those in which the coaxing was started at a lower stress.

5. The damage due to overstressing for 30 per cent cycle ratio at a stress 10 per cent above the fatigue limit was eliminated by understressing. Damage due to stressing 30 per cent above the fatigue limit was not completely eliminated by understressing.

6. The elimination of damage by understressing was verified by a test in which a program of overstressing followed by understressing was repeated 25 times for a cumulative cycle ratio at the overstress of 7.6 without fracture.

7. Strain aging was not a factor in the improved fatigue limit of this material due to coaxing.

Acknowledgment:

Harold Hessing planned and conducted some of the early portions of this investigation. A part of the work was carried out under the sponsorship of the Air Materiel Command, U. S. Air Force.

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(5) J. A. Bennett, "A Study of the Damaging Effect of Fatigue Stressing on SAE X4130," *Proceedings*, Am. Soc. Testing Mats., Vol. 46, p. 693 (1946).

(6) "Manual on Fatigue Testing," Am. Soc. Testing Mats. (1949). (Issued as a separate publication *ASTM STP No. 91.*)

(7) J. A. Bennett and J. G. Weinberg, "Fatigue Notch Sensitivity of Some Aluminum Alloys," *Journal of Research*, Nat. Bureau Standards, Vol. 52, May, 1954, p. 235. (*RP 2495.*)

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DISCUSSION

Mr. G. M. Sinclair.[1]—The statement made by the authors that specimens coated with a rust-preventive oil showed greater fatigue resistance than oil-free specimens is of interest in relation to a recent study by W. Weibull.[2] Briefly, Weibull reports that specimens of 75 S-T aluminum alloy coated with kerosine have a much increased fatigue life compared to uncoated specimens. The mechanism whereby fatigue life is increased by a surface coating of oil or kerosine is not clear and might be a worthy subject for further investigation.

I do not believe that the results of the present study justify the conclusion by the authors that strain aging was not a factor in the improved fatigue limit of the steel due to coaxing. This conclusion was based primarily upon two points: (1) no evidence of strain aging was observed in the static stress-strain curves and (2) the improvement in fatigue limit due to coaxing was greater when the initial stress was 86,000 psi than when it was 80,000 psi.

With regard to the first point, I am certain that the authors are aware that the initiation of fatigue damage is a highly localized phenomenon and that failure to detect macroscopic evidence of strain aging in a tension test does not constitute proof that the fatigue behavior is unaffected by strain aging. I suggest rather that coaxing experiments conducted at low and at elevated temperatures would provide a better means for resolving the question.

Considering now the second point, it was not established in the paper that the difference between results obtained for an initial stress of 80,000 psi and for an initial stress of 86,000 was statistically significant. If it is assumed that the difference is significant, one is forced to conclude that some form of *damage* is caused by initiating the understressing at 80,000 psi. Since the authors have stated that fatigue damage due to mild *overstressing* was repaired by coaxing, an irreparable damage which occurs during *understressing* is quite difficult to visualize. I would like to have the authors' comments regarding these questions.

Messrs. H. E. Frankel and J. A. Bennett (*authors*).—We would like to thank Mr. Sinclair for bringing to our attention Weibull's study of kerosine-coated 75S-T aluminum alloy. The mechanism by which the kerosine and oil act to increase fatigue life presents a possibly fruitful area of research.

Mr. Sinclair points out that our failure to detect macroscopic evidences of strain aging does not necessarily negate the hypothesis that coaxing is associated with strain-aging phenomena. Certainly it is possible that the mechanism of coaxing may be similar to that of strain aging, but we wished to point out that it is possible to obtain coaxing in materials such as this that do not strain-age in the usual sense of the term.

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[1] Research, Associate Professor, Department of Theoretical and Applied Mechanics, University of Illinois, Urbana, Ill.

[2] Waloddi Weibull, "The Propagation of Fatigue Cracks in Light-Alloy Plates," Svenska Aeroplan Artiebolaget Technical Note 25, Linkoping, Sweden (1954).

The other point raised by Mr. Sinclair, that the difference in coaxing behavior between specimens that were coaxed from 86,000 psi and those coaxed from 80,000, would "force one to conclude that some form of *damage* is caused by initiating the understressing at 80,000 psi," does not seem to be warranted. Understressing, regardless of where begun, improved the basic fatigue properties of the material. Considering the complexity of the phenomenon, it is perhaps not surprising that one obtains anomalous results such as these, but we do not feel that we are yet in any position to attempt to explain them.

MR. J. T. RANSOM.[3]—With regard to strain aging, I do not think one can categorically say that SAE 4340 steel does not strain age. We have quite a bit of evidence that it does.

I do not believe the authors have given any explanation of what the oil did do. They indicated that the oil has a pronounced effect upon fatigue limit, and yet say that it is not a corrosion effect. Do they have any idea what the mechanism of the effect is?

MR. FRANKEL (*author*).—To determine whether or not there had been a chemical reaction between the oil and the specimens that might have removed microcracks, we took several small disks, carefully weighed them, cleaned them and then put them in oil. Reweighing at intervals over a period of several months indicated no significant weight change. Therefore, we came to the conclusion that it was not a chemical effect.

As for the actual mechanism involved, it is still in doubt.

MR. G. R. GOHN.[4]—I would like to add one bit of information on the effect of oil.

Back in 1944, in a joint session of the AIME and ASTM, Ferguson and Bouton[5] showed that the addition of certain oils or greases to cable sheath tested in bending might increase the fatigue life in the plastic range by as much as eight- or ten-fold. On the other hand, certain other greases would reduce the fatigue life by factors of a third to a tenth, and this effect is closely associated with the wetting characteristics of the particular grease or oil.

MR. J. C. LEVY (*by letter*).[6]—Towards the end of this paper it is pointed out that the tempered martensitic steel used in the investigation did not appear to strain age in a tension test. Thus it was concluded that the coaxing effect in this material is independent of strain-aging ability. This conclusion is, as the authors mention, in contrast to that arrived at by Sinclair and also apparently to some work being carried out at the National Physical Laboratory in England.[7]

Figure 10 seems to show a permanent set of about 0.3 per cent before the tension test was interrupted. This is perhaps rather a small amount to encourage strain aging although it can certainly be accepted that this material would not be expected to strain age readily.

However even if a material fails to strain age in a tensile overstrain test this is not necessarily a guarantee that it cannot strain age in a fatigue test. Metallurgical changes may possibly take place in high-strength steels subjected to fluctuating load analogous to changes recently observed in a high-strength light alloy. Hanstock[8] found that in DTD 683 (similar to 75S-T) localized bands of precipitation (over-aging) occurred before the formation of fatigue cracks. These bands created "soft spots" into which the cracks afterwards penetrated.

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[3] Engineering Research Laboratory, Engineering Department, E. I. Du Pont de Nemours and Co., Inc., Wilmington, Del.

[4] Supervisor, Creep and Fatigue Laboratories, Bell Telephone Labs., Inc., New York, N. Y.

[5] Lawrence Ferguson and George M. Booton, "The Effect of a Coating of Polybutene on the Fatigue Properties of Lead Alloys," Symposium on Stress Corrosion Cracking of Metals, Am. Soc. Testing Mats., p. 473 (1944). (Issued as separate publication *STP No. 64*.)

[6] Lecturer, Civil and Mechanical Engineering Dept., Northampton Polytechnic, London, England.

[7] "Progress in Metallurgical Research," *Metallurgia*, Vol. 52, No. 309, p. 20, July, 1955.

Also, in the discussion of Hanstock's paper,[9] other evidence was enumerated to suggest that high temperatures exist in the region of slip bands formed in fatigue. If this is so it may mean that in steel a martensitic structure could break down and give rise to a certain amount of free ferrite in which strain aging could take place. Under such conditions, the coaxing procedure would enable the elastic limit to be raised, by strain aging in the very regions being attacked by fatigue. It would be most interesting if the authors could say whether there is any evidence of metallurgical changes occurring where cracks initiated in their specimens. Possibly, however, the resulting structure would be too fine for microscopic interpretation to be made.

MR. FRANKEL.—We would like to thank Mr. Levy for his comments.

As pointed out previously, it certainly is possible that strain aging on a microscopic scale could conceivably occur. However, metallographic examination indicated no evidence of this. As suggested by Mr. Levy, perhaps the resulting changes are too fine to be resolved microscopically.

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[8] R. F. Hanstock, "Fatigue Phenomena in High-Strength Aluminum Alloys," *Journal*, Inst. Metals, Vol. 83, Part I, p. 11, Sept., 1954.

[9] "Discussion on Fatigue," *Journal*, Inst. Metals, Vol. 83, Part 12, p. 528, Aug., 1955.

ON FATIGUE TESTS UNDER PROGRESSIVE STRESS[*]

By Nobusuke Enomoto[1]

Fatigue test experiments have been made by Prot (**1**)[2] with the stress increasing with the number of stress cycles instead of being kept constant. According to Prot, the relation between the stress at failure and the square root of the rate of stress increment is almost a straight line whose intersection with the stress axis determines the fatigue limit. Described in the present paper are the experiments conducted on three metals to verify the correctness of this method. Mild steel, aluminum alloy (duralumin), and brass have been tested by the Prot method, and the results have shown that there exist almost straight-line relations between the stress at failure and a quarter power of the rate of stress increment. The intersections of these lines with the stress axis have been verified to correspond very closely to the fatigue limit. From the standpoint of internal lost energy needed for fatigue failure, the above relations have been derived theoretically from simple assumptions; as a result they are found to have a relation to the *S-N* curve. The fatigue test employing progressive stress has been ascertained to be effective as a quick way of determining the fatigue limit.

Mechanism of Progressive Load Fatigue Testing Machine

The weight hanger of a rotating-beam fatigue testing machine has been modified to travel along a lever, one end of which is supported on a fixed knife edge and the other hung on a loading bar directly below the specimen; the weight hanger travels following a screw guide (Fig. 1). *R* is the loading bar directly below the specimen; the lever, *L*, is supported between a knife edge, *K*, at the lower end of *R* and a fixed knife edge, *F*. The weight, *W*, is hung on the lever by a roller bearing, *B*. When a pulley, *P*, is driven by a synchronous motor, a screw, *S*, is rotated with its turning speed reduced by worm and worm gear, *G*; a square nut, *N*, travels along this screw. Because one end of the shaft of the roller bearing fits in a groove of the square nut

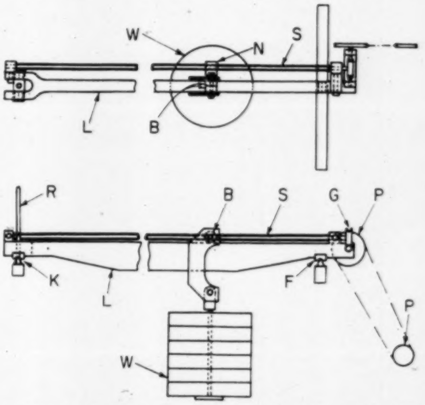

Fig. 1.—Diagram of the Loading Weight Traveling Device.

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[*] Presented by title at the Fifty-seventh Annual Meeting of the Society, June 13–18, 1954.

[1] Railway Technical Research Inst., Japanese National Railways, Tokyo, Japan.

[2] The boldface numbers in parentheses refer to the list of references appended to this paper, see p. 917.

which is perpendicular to the screw shaft, the weight, *W*, travels along the lever, and the deflection of the lever produces no strain on the screw shaft.

The traveling speed of the weight is varied by changing the diameter of the driven or of the driving pulley. The distance between knife edges on the ends of the lever is 1 m. The rotating fatigue test is started when the roller bearing is just above the knife edge, *F*. In this position the balancing weights on both sides of the rotating bean shaft have been adjusted in advance to balance with lever *L*, screw *S*, and bar *R*, and consequently to make the bending stress of the specimen zero.

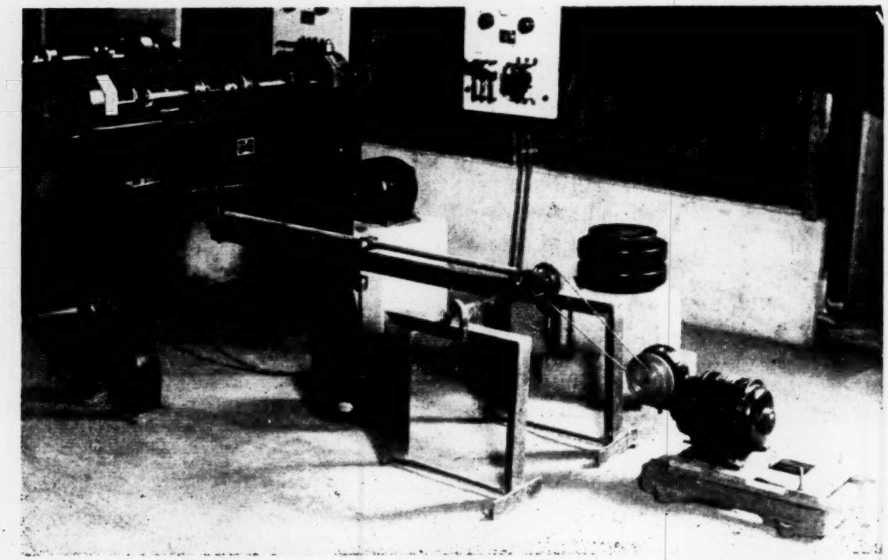


FIG. 2.—Device for Progressive Stress Fatigue Test.

TABLE I.—CHEMICAL COMPOSITIONS AND MECHANICAL PROPERTIES OF MATERIALS.

Material	Chemical Composition, per cent	Modulus of Elasticity, psi	Ultimate Tensile Strength, psi	Yield Strength, psi	Elongation, per cent
Mild steel	Cu 0.08	30.77×10^6	69 800	52 000	32.7
Duralumin	Cu 3.77, Mg 0.77, Mn 0.33, Fe 0.50, Si 0.39	10.92	56 100	...	26.2
Brass	Cu 67.21, Zn remainder	15.32	54 300	...	35.4

It is desirable that the weight be moved by the driving shaft of the testing machine, but in this case another synchronous motor of 0.1 hp was used temporarily to drive it. The relation between the number of stress cycles and the traveling distance of weight was practically linear.

An electric circuit cut-off device is attached in order to stop the main motor and the weight-moving motor automatically at the instant of specimen failure. A photograph of the testing machine is shown in Fig. 2.

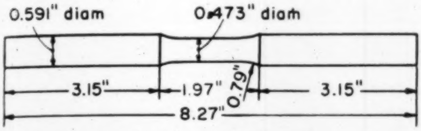


FIG. 3.—Rotating-Beam Specimen.

SPECIMENS

Compositions and mechanical properties of the materials are presented in Table I. The form of specimen is shown in Fig. 3. Mild steel specimens were machined to final dimensions since they were not heat treated. Both ends of the duralumin and brass specimens were

TABLE II.—RESULTS OF ROTATING-BEAM FATIGUE TESTS UNDER PROGRESSIVE STRESS.

Specimen	Stress at Failure, S_p, psi	Cycles to Failure, N_p	$\tan \alpha = \frac{S_p}{N_p}$	$\tan^{1/2} \alpha$	$\tan^{1/4} \alpha$	Rockewll Hardness, B Scale
MILD STEEL						
No. 21	59 690	126 500	0.472	0.687	0.829	66.1
No. 17	61 620	132 900	0.463	0.681	0.825	64.2
No. 13	54 870	306 500	0.179	0.423	0.651	63.4
No. 20	52 860	412 400	0.128	0.358	0.598	65.2
No. 15	48 900	1 315 500	0.0371	0.193	0.439	60.4
No. 14	46 930	2 198 500	0.0213	0.146	0.382	63.0
No. 22	40 630	5 315 500	0.0076	0.0875	0.296	67.1
No. 23	43 850	5 752 500	0.0076	0.0873	0.296	65.5
No. 18	41 480	5 424 300	0.0076	0.0872	0.295	64.3
No. 16	44 210	5 923 500	0.0075	0.0864	0.294	65.7
No. 28	40 120	30 956 500	0.0013	0.0360	0.190	65.6
No. 26	37 210	30 129 800	0.0012	0.0351	0.187	66.6
No. 19	41 720	42 042 000	0.0010	0.0315	0.178	65.4
DURALUMIN						
No. 24	47 420	109 800	0.432	0.657	0.811	62.3
No. 25	44 840	152 000	0.295	0.543	0.738	60.5
No. 23	41 620	325 000	0.128	0.358	0.598	57.2
No. 22	40 140	318 000	0.126	0.355	0.596	56.5
No. 21	35 500	1 032 500	0.0344	0.185	0.431	55.7
No. 18	36 780	1 185 500	0.0310	0.176	0.420	54.0
No. 16	33 320	1 574 060	0.0212	0.145	0.382	54.9
No. 17	32 950	1 598 160	0.0206	0.144	0.379	54.9
No. 19	30 400	4 130 000	0.0074	0.0858	0.293	55.6
No. 27	26 920	7 254 500	0.0037	0.0609	0.247	56.5
No. 20	25 460	8 367 700	0.0030	0.0552	0.235	54.7
No. 28	24 470	24 332 700	0.0010	0.0317	0.178	52.3
BRASS						
No. 21	47 390	100 000	0.474	0.688	0.830	64.8
No. 12	50 950	111 500	0.457	0.676	0.823	63.8
No. 14	35 880	989 100	0.0363	0.190	0.436	62.8
No. 18	34 950	970 400	0.0360	0.190	0.436	62.9
No. 20	32 520	1 578 500	0.0206	0.144	0.379	62.7
No. 13	33 620	1 634 900	0.0206	0.143	0.379	62.5
No. 19	30 120	4 104 600	0.00734	0.0857	0.292	61.6
No. 17	24 200	10 437 900	0.00232	0.0481	0.219	61.4
No. 25	22 550	10 407 500	0.00217	0.0465	0.216	62.4

machined to 0.67 in. in diameter (the middle parallel parts were machined as in Fig. 3), heat treated, and then machined to 0.591 in. in diameter. This was done to correct the warping of specimens due to heat treating.

The duralumin specimens were heated at 932 F for 30 min and cooled in water, whereas the brass specimens were annealed for 1 hr at 1110 F. The mild steel specimens were not heat treated. Rockwell B hardness numbers were measured at the gripping surfaces of specimens before the fatigue test.

TESTING PROCEDURE AND RESULTS

Fatigue tests under progressive stress were carried out varying the rate of stress increment of each specimen, and the relations between the stress at failure and the rate of stress increment were obtained.

The results for each material are shown in Table II. The Rockwell hardness numbers are the mean values measured at the gripping surfaces before fatigue tests. Figure 4 is an S-N diagram of the test results. Figure 5 shows the relation between the stress at failure and $(S_p/N_p)^{\frac{1}{2}}$ in Table II in which the curves are theoretical ones described in the next section of the paper. The points plotted on the ordinate are endurance limits obtained from Fig. 4. From this diagram, the relations between the stress at failure and $\tan^{\frac{1}{2}} \alpha (= \sqrt{S_p/N_p})$ are clearly seen in sharp curves; it is difficult to determine the fatigue limit from this

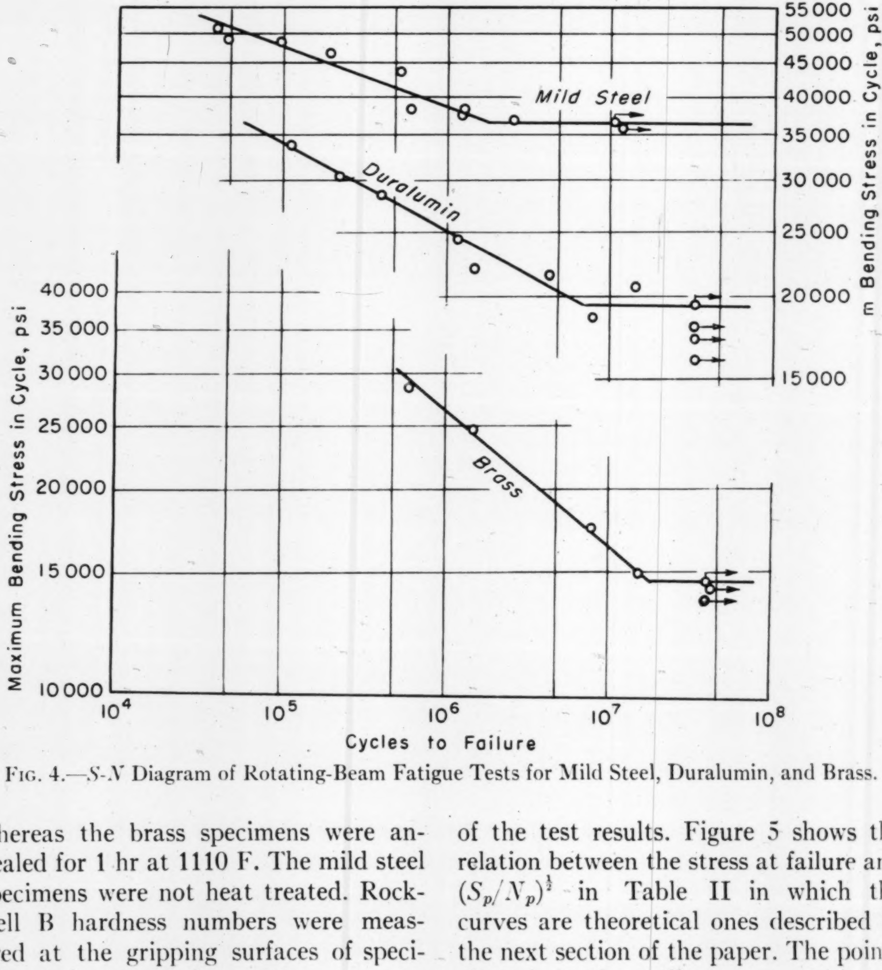


FIG. 4.—S-N Diagram of Rotating-Beam Fatigue Tests for Mild Steel, Duralumin, and Brass.

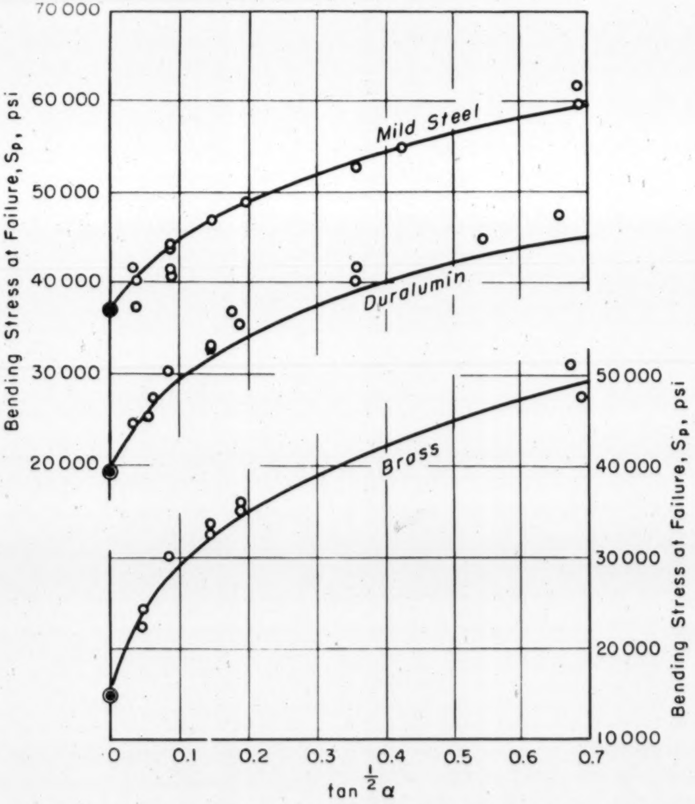


FIG. 5.—S_p − $\tan^{\frac{1}{2}} \alpha$ Curve of Rotating-Beam Fatigue Tests Under Progressive Stress.

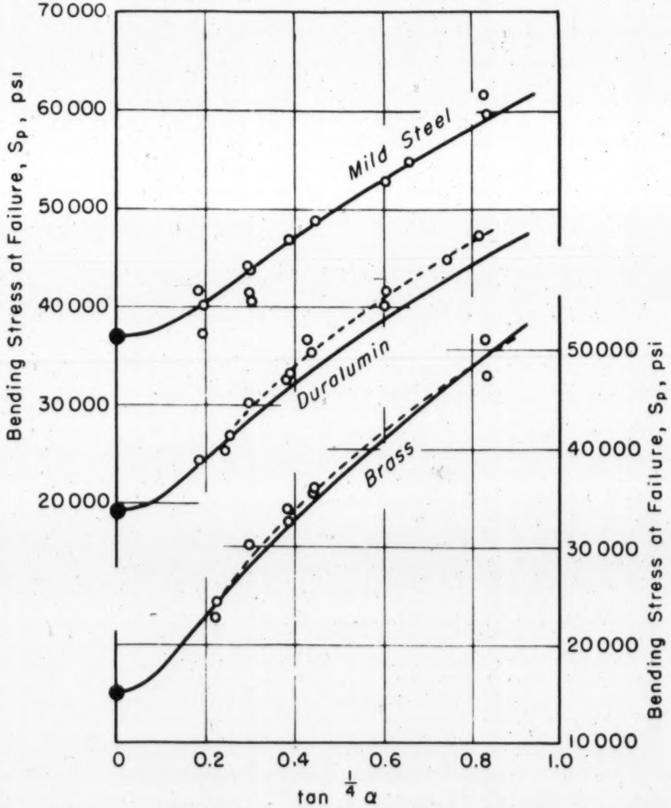


FIG. 6.—S_p − $\tan^{\frac{1}{4}} \alpha$ Curve of Rotating-Beam Fatigue Tests Under Progressive Stress.

diagram by extrapolation. The relations of stress at rupture and $(S_p/N_p)^{\tan^{\frac{1}{m}}\alpha}$ in Fig. 6 are almost in straight lines, extrapolating very closely to the values of fatigue limit at the point of intersection on the ordinate.

S-N CURVE AND S_p - $\tan^{\frac{1}{m}}\alpha$ CURVE

The author has observed previously the variation that occurs in the logarithmic decrement of vibration when mild steel, aluminum, brass, etc., are repeatedly stressed (**2**). According to this observation the damping capacity before the fatigue test was generally represented by the form of curve A in Fig. 7. After a great number of stress cycles of S_1 (larger than the stress of endurance limit), the damping capacity curve was represented by curve B. If the stress were larger, S_2, the damping capacity increased according to curve C.

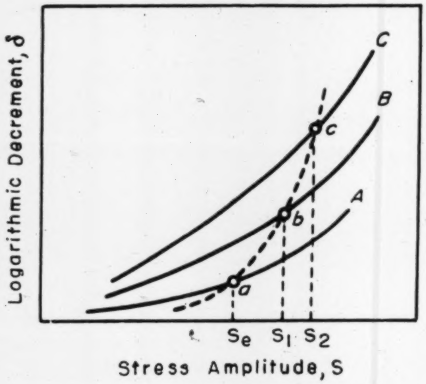


FIG. 7.—Variation of Internal Friction Due to Fatigue.

Now suppose that when a specimen is subjected to repeated stress of endurance limit S_e, the internal friction in the specimen is point a. Suppose also that the internal friction is at points b and c when the stresses are S_1 and S_2, respectively. Also assume the shape of the curve a-b-c (dotted line in Fig. 7) to be:

$$\delta = aS^n \quad \text{.............} (1)$$

where a and n are constants for each material.

Further, the relation between δ and the amount of lost work in one cycle ΔW is known as:

$$\Delta W/W \cong 2\delta \quad \text{.............} (2)$$

where:

W = total vibrational energy and
$\Delta W/W$ = specific loss.

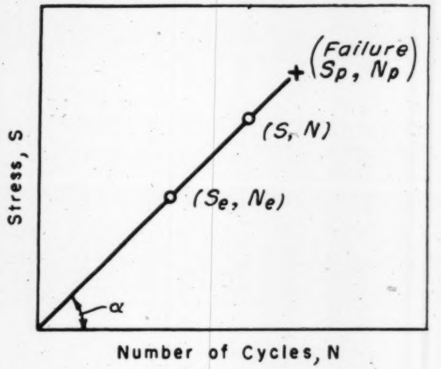


FIG. 8.—Relation Between S and N in Fatigue Test Under Progressive Stress.

From both equations we have:

$$\Delta W/W = aS^n$$

or:

$$\Delta W = cS^{n+2}, \qquad c = a/2E \quad \text{.....} (3)$$

where E = modulus of elasticity.

Again, let us assume that for a metal, to which repeated load is applied over the stress of fatigue limit, the part of the energy dissipated as plastic internal friction which exceeds a certain amount in one cycle is assumed to contribute to fatigue failure, and the metal is assumed to rupture when such energy is accumulated to a certain amount after a number of stress cycles.

The logarithmic decrement of vibration appearing due to the internal friction within this safe range is shown by

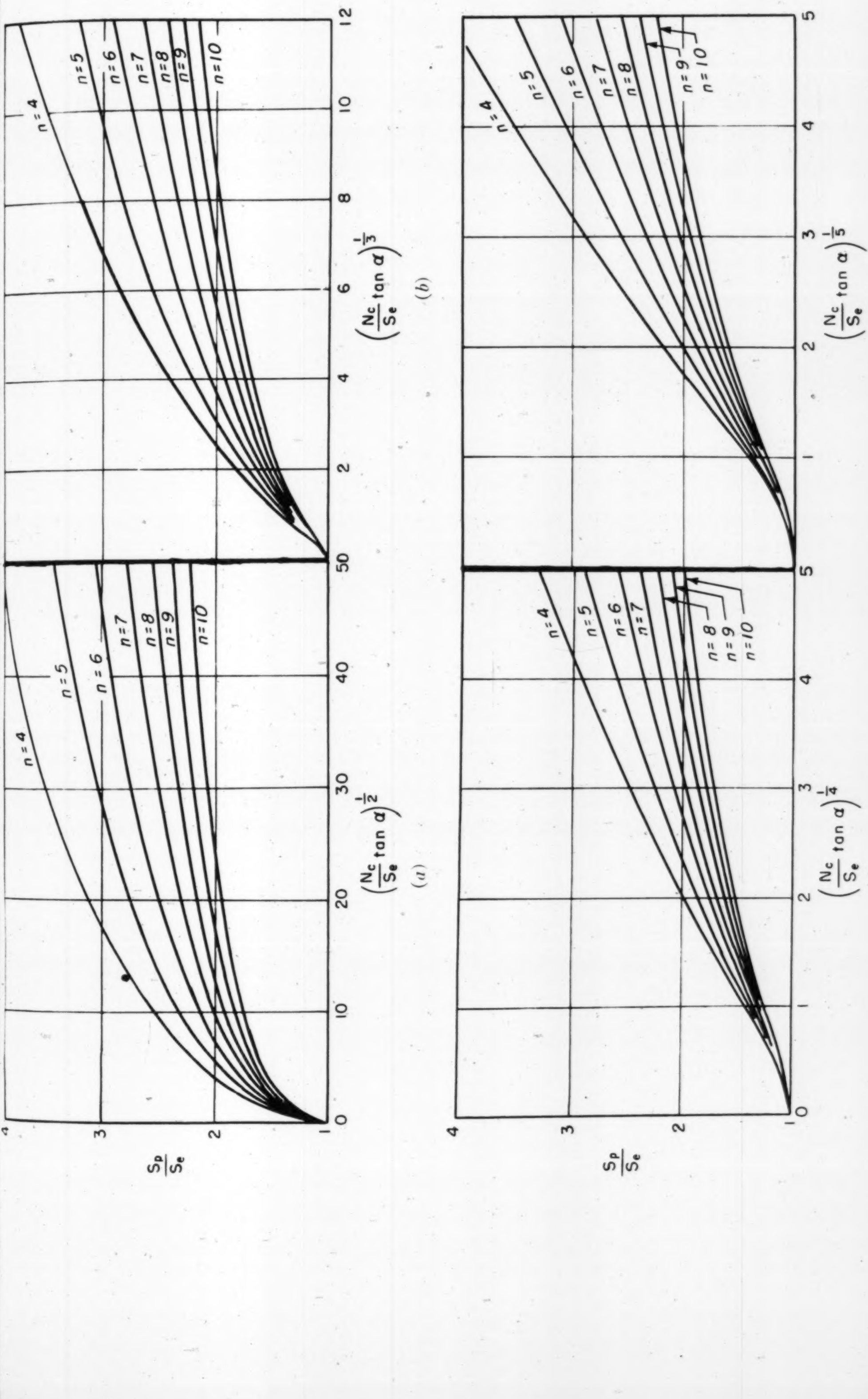


FIG. 9.—Relation Between the Stress at Failure and the Rate of Stress Increment.

point A in Fig. 7. This critical internal energy loss ΔW_e is, according to Eq 3:

$$\Delta W_e = 2\delta W_e = cS_e^{n+2}$$

The energy contributed to failure in one cycle is therefore:

$$\Delta W - \Delta W_e = c(S^{n+2} - S_e^{n+2}) \ldots (4)$$

Next, in the case of fatigue test under progressive stress as shown in Fig. 8:

$$N = S \cot \alpha, \qquad dN = \cot \alpha \, dS$$

and the energy contributed to fatigue failure during the dN cycle is $c\ (S^{n+2} - S_e^{n+2})\ dN$. Then the total energy contributed to rupture is given by:

$$W = \int_{N_e}^{N_p} c(S^{n+2} - S_e^{n+2})\, dN$$

$$= c \cot \alpha \int_{S_e}^{S_p} (S^{n+2} - S_e^{n+2})\, dS$$

$$= c \cot \alpha \left[\frac{1}{n+3} (S_p^{n+3} - S_e^{n+3}) - S_e^{n+2}(S_p - S_e) \right] \ldots (5)$$

Further, assume that the amount of energy contributed to fatigue failure is constant and independent of the rate of stress increment $\tan \alpha$. Then:

$$K = c \cot \alpha \left[\frac{1}{n+3} S_p^{n+3} - S_e^{n+2} S_p + \frac{n+2}{n+3} S_e^{n+3} \right] \ldots (6)$$

or

$$\tan \alpha = \frac{S_e}{N_c} \left[\frac{1}{n+3} \left(\frac{S_p}{S_e} \right)^{n+3} - \frac{S_p}{S_e} + \frac{n+2}{n+3} \right], \qquad N_c = \frac{K}{c} \Big/ S_e^{n+2} \ldots (6a)$$

Substituting $n = 4, 5, 6 \ldots 10$ in Eq 6a, the relation between S_p/S_e and $[(N_c/S_e) \tan \alpha]^{\frac{1}{m}}$ (where $m = 2, 3, 4, 5$) is computed and is presented in Fig. 9(a), (b), (c) and (d). It is found that the curves in Figs. 9(a) and (c) resemble qualitatively the test data shown in Figs. 5 and 6, respectively.

Next, the idea used above is applied to the S-N diagram. Since the energy contributed to fatigue failure is given by Eq 4, assuming that the specimen fails when this energy reaches a definite amount K, then:

$$K = c(S^{n+2} - S_e^{n+2})N \ldots \ldots (7)$$

Taking the logarithm of both sides and expressing in the form S/S_e, we get:

$$\log N = \log \left(\frac{K}{c} \Big/ S_e^{n+2} \right) - \log \left[\left(\frac{S}{S_e} \right)^{n+2} - 1 \right]$$

$$= \log N_c - \log \left[\left(\frac{S}{S_e} \right)^{n+2} - 1 \right],$$

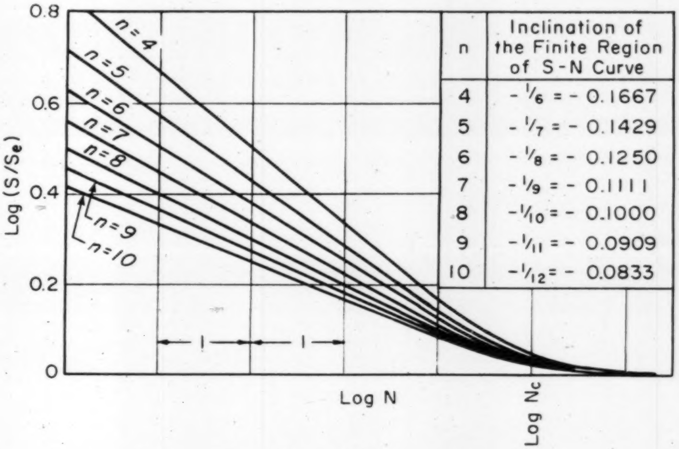
$$c = \frac{a}{2E} \quad (8)$$

This is the equation of the S-N curve, in which S is the stress at failure. If we look for the relation between $\log\ (S/S_e)$ and $\log N$ in the case $n = 4, 5, 6, \ldots 10$, we get Fig. 10. In Eq 7, since S_e^{n+2} can be neglected against S^{n+2} when the cyclic stress is much larger than the fatigue limit, this equation gives an asymptote of the finite region of the S-N curve; the slope of the curve in this region is seen as $-1/(n+2)$. The critical number of stress cycles, N_c, which is indicated as the point of intersection of this asymptote and the line of infinite region (parallel to N-axis), is given by $\frac{K}{c}/S_e^{n+2}$.

DISCUSSION OF RESULTS

Experimental Relation Between the S-N Curve and the S_p - tan α Curve in the Fatigue Test Under Progressive Stress:

From the S-N curves in Fig. 4, the fatigue limits, the critical numbers of stress cycles, and the slope of the finite region of the S-N curves have been obtained for each material tested. These have been substituted in Eq 6a to get the relations between the stress at rupture, S_p, and the rate of stress increment, tan α, which are shown by the real curves in Figs. 5 and 6. These curves deviate somewhat from the test points on duralumin, whereas on mild steel and brass they agree fairly well with the test points.



n	Inclination of the Finite Region of S-N Curve
4	$-1/6 = -0.1667$
5	$-1/7 = -0.1429$
6	$-1/8 = -0.1250$
7	$-1/9 = -0.1111$
8	$-1/10 = -0.1000$
9	$-1/11 = -0.0909$
10	$-1/12 = -0.0833$

FIG. 10.—S-N Diagram.

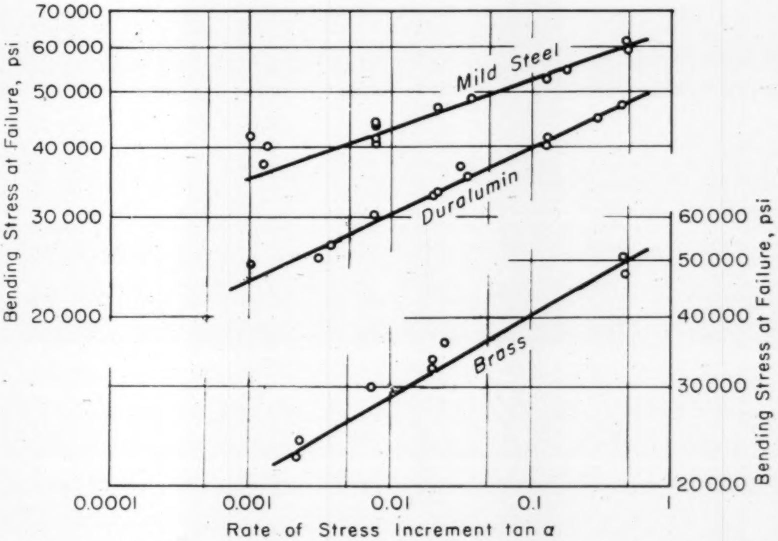


FIG. 11.—Fatigue Tests Under Progressive Stress, Replotted on Log-Log Scale.

Figure 11 shows the experimental relation between S_p and tan α with logarithmic coordinates. The equation of asymptotes of these curves are obtained ignoring the second and third terms of the right-hand side of Eq 6 which are negligible as compared with the first term. Since the inclination of the asymptotes is $1/(n + 3)$, the values of n can be computed.

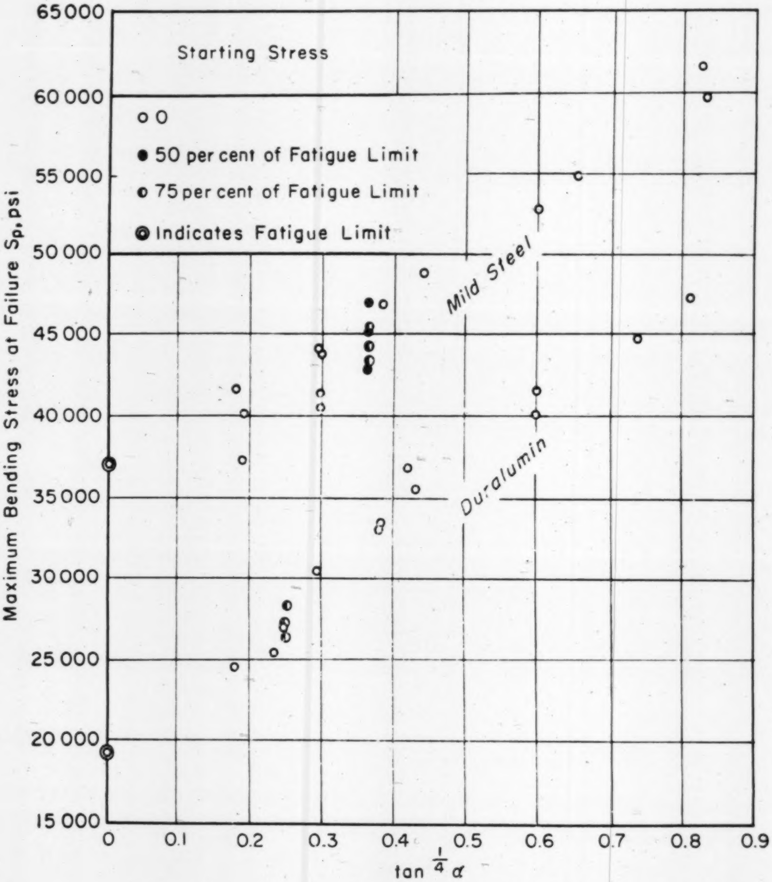


FIG. 12.—S_p − $\operatorname{Tan}^{\frac{1}{4}} \alpha$ Curve of Rotating-Beam Fatigue Tests Under Progressive Stress Which Is Started from Zero and a Certain Value of Stress.

Critical Number of Stress Cycles and the Fatigue Limit:

The number of stress cycles at the intersection of the straight-line part of the finite region and the line of the infinite region on the logarithmic S-N curve—that is, the critical number of stress cycles—is considered to be in the order of 10^6 for ferrous metals and of 10^7 to 10^8 or more for non-ferrous metals. There are cases, however, when, the bend of the S-N curve is loose and the critical number of stress cycles is not distinct, depending upon the materials or the condition of repeated stress. This is the case, for instance, when there is a notch effect or when corrosion progresses in the course of cyclic loading; these become major causes of fatigue failure. The concept of fatigue failure that Eq 4 describes can be applied to the materials which have the critical number of stress cycles in the S-N curve. In this case, the critical number of stress cycles, N_c in Eq 8, is given by $K/(cS_e^{n+2})$ (see Fig. 10). The value of N_c is determined by K, $c = a/(2E)$, S_e, and n, which are the characteristic constants of a material under given conditions. Consequently, this means that N_c is dependent on the physical conditions.

In the equation of the S-N curve (Eq 8), if the straight part of the finite region can be determined by experiment, n is determined from its inclination. Moreover, if two points (S_1, N_1), (S_2, N_2) on the finite region are obtained from tests, then N_c and S_e can be computed. However, both (1) the straight part of the finite region of the S-N curve which is, strictly speaking, the asymptote, and (2) the deviation of the two points from this straight line are important factors in determining N_c and S_e, since this deviation is practically so small that it is difficult to calculate it with sufficient assurance.

Fatigue Tests Under Progressive Stress Which Is Started from a Certain Value of Stress:

All of the progressive stress fatigue tests described above were begun from zero stress, but the case when the test begins in the middle of the progressive stress range on mild steel and duralumin was also studied. (Because brass specimens were in short supply, the influence was not studied.) Tests were begun with stresses of 50 and 75 per cent of the fatigue limit. Figure 12 shows Fig. 6 with these points plotted supplementally.

From these results, it is seen that no difference in effects have been observed between the case when a test begins from zero stress and the cases when it begins from the stress of 50 or 75 per cent of the fatigue limit. This means that the assumption, internal loss of energy less than a certain amount in one cycle of repeated stress contributes nothing to fatigue failure, is correct experimentally.

TABLE III.—ERRORS IN FATIGUE LIMIT INFERRED FROM S_p-$\tan^{1/4} \alpha$ CURVE BY EXTRAPOLATION.

Material	S_e, psi	$S_{e(1-8)}$, psi	$S_{e(1-24)}$, psi	$\frac{S_{e(1-8)} - S_e}{S_e}$, per cent	$\frac{S_{e(1-24)} - S_e}{S_e}$, per cent
Mild steel..........	36 800	34 600	34 600	−6.2	−6.0
Duralumin.........	19 200	22 500	20 600	17.2	7.3
Brass..............	14 900	18 900	17 800	26.8	19.5

Progressive Stress Fatigue Test as Quick Method to Determine the Fatigue Limit:

Under the premise that there is a connection as indicated in Eqs 6*a* and 8 between the S-N curve and the S_p-$\tan \alpha$ curve obtained by the progressive stress method, the S_p-$\tan \alpha$ curve has been studied to ascertain its usefulness for estimating the fatigue limit.

For instance, in Fig. 5 it is difficult to determine the values on the ordinate by extending the experimental curves because n and N_c are not known. We investigate the case of the curves in Fig. 9(*c*) where the abscissa is measured with the scale of $\tan^{\frac{1}{4}} \alpha$, that is, the case whose curves are comparatively linear. The speed of the testing machine used here is 2090 rpm. The time necessary for rupture of a specimen based on such speed and the value of $\tan^{\frac{1}{4}} \alpha$ on each material from the experimental curves can be computed from Fig. 6 (indicated in dotted lines). Further, on a test curve in Fig. 6 both the point of rupture in 1 hr, S_1, and that of 8 hr, S_8, are joined with a straight line, and next, the point of ruptue in 1 hr, S_1, and in 24 hr, S_{24}, are joined in the same manner. These lines are extended, respectively to the ordinate, and the values of intersecting points with it are marked $S_{e(1-8)}$ and $S_{e(1-24)}$, respectively. Then the values of ratio $[S_{e(1-8)} - S_e]/S_e$ and $[S_{e(1-24)} - S_e]/S_e$ are obtained as in Table III.

If we compare $S_{e(1-8)}$ and $S_{e(1-24)}$ with S_e in this table, we see somewhat smaller values on mild steel and larger ones on the others. This can be expected in view of the form of the S-tan$^{\frac{1}{4}}$ α curves in Fig. 9(*c*) introduced theoretically; that is, in accordance with the material or with the value of n, the former ($S_{e(1-8)}$ or $S_{e(1-24)}$) will be larger or smaller than the latter (S_e). The inferred values of fatigue stress $S_{e(1-8)}$ and $S_{e(1-24)}$ obtained by the above described method will be made to approach S_e by proper modification. For instance, assume $S_{e(1-8)}$ to be a temporary fatigue limit and compute the values $S_1/S_{e(1-8)}$ and $S_8/S_{e(1-8)}$. Next set the value n by means of the method in Fig. 11; then look for the above two points on a curve having a nearest value of n among the group of curves in Fig. 9(*c*) and join them with a straight line, extending it to the ordinate. As the value of this intersecting point is larger or smaller than 1, $S_{e(1-8)}$ may be corrected by that difference.

Now let us investigate whether this method of inferring the fatigue limit by using the S_p-tan α curve is effective as a quick method. When we adopt $S_{e(1-24)}$, if five specimens are used to find each value of S_1 and S_{24}, respectively, a total of 125 hr is necessary for test, whereas if the tests were begun from about half stress of fatigue limit for finding S_{24}, 88 hr would suffice. In the same manner, when $S_{e(1-8)}$ is used, from 32 to 41 hr are required. In the test to look for the S-N curve on iron or steel specimens, if the test is stopped at 5×10^6 stress cycles for not-failed specimens, and at 8×10^5 stress cycles for failed ones, and if three specimens are not failed but seven are, then since the total required hours for tests are about 165, the former method can be said to make a considerable saving in testing hours compared with the latter. Further, in the case of non-ferrous metals on which the test continues up to 10^7 or 10^8 cycles, about 350 to 2500 hr are required for finding an endurance limit. Here again, the former method will be a great time-saver.

In short, the progressive stress method is effective as a quick method to determine the fatigue limit, both for ferrous and non-ferrous metals.

Especially in the case when the supply of specimens is short, the ordinary method of fatigue testing is sometimes time consuming or liable to fail because it misses the aim of the value of the fatigue limit. On the other hand, in the progressive stress method all of the test results are useful in determining the fatigue limit.

In the case where the fatigue limit is controlled by the stress raiser or condition of the surface of the specimen, it is not clear whether this method is useful. Further studies are needed.

Hypotheses of Fatigue Failures:

The assumptions concerning fatigue mechanism which have been mentioned in this paper are as follows:

1. The energy lost by internal friction, beyond a certain amount in one cycle of repeated stress, contributes to fatigue failure.

2. The total amount of internal lost energy per unit volume which has contributed to fatigue failure is constant, so long as the material and its state are the same.

3. In the vibration of metals there is the following relation between the logarithmic decrement, δ, and the stress

amplitude, S:

$$\delta = aS^n$$

The first of these assumptions which premises the existence of the endurance limit means that the specimen has a dissipation of energy by internal friction under repeated stress even below this limit. Therefore, the case of a material in which the existence of fatigue limit is vague is not included here. The existence of the loss of energy due to plastic internal friction under a stress amplitude even below the fatigue limit can be confirmed by its measurement. The remainder of this loss of energy, after being partially transformed into heat by the motion of dislocations, accumulates in the material in the form of internal strains. This is seen by the fact that lattice deformations have been recognized clearly by means of X-ray observation. Under repeated stress within the fatigue limit, a metal may be considered to come to an equilibrium state when the lattice strain reaches a certain amount but does not cause so sharp a stress concentration as to become a source of crack; the work applied thereafter may be considered to transform all into heat. This transformation can be considered to be carried out by the swinging motion of the increased free dislocations.

Moreover, of these lost energies, there is a case involving that due to thermoelasticity but considered not to contribute to fatigue cracking, because the internal friction due to thermoelasticity is not accompanied by a slip which constitutes a stage in the process of crack growth. Besides, this internal friction is independent of stress amplitude, and the friction that increases under increased repeating stress is due to plasticity (**3**).

In the second assumption, the influence of understressing and coaxing must be examined in the progressive stress test. According to the study of Sinclair (**4**) the increase in fatigue strength due to understressing and coaxing has been claimed experimentally to depend rather on strain aging—that is, the factor of time—than on the effect of work hardening. According to this, the influences mentioned above may be considered to be avoidable in the fatigue test under progressive stress except in the case when the strain-aging property of a specimen is remarkable or the test extends over an especially long time. Where the repeated stress is near to the fatigue limit, understressing acts effectively. The times of applying stress from a half to full stress of fatigue limit were computed for those specimens having the smallest stress increment in fatigue tests under progressive stress. The times were about 148 hr for specimen No. 19 of mild steel, about 76 hr for No. 28 of duralumin, and about 27.5 hr for No. 25 of brass. Though the strain aging of mild steel specimens which were as-received and were not heat treated is not expected to be so great, the influence of it may have appeared in specimen No. 19 since the duration of applying the understressing to it was long. On the specimens of duralumin and brass, the strain aging must be evident in some degree, but even on the duralumin specimen No. 28 or the brass specimen No. 25, in which the rates of stress increment were small, the deviations from the theoretical curves are not observed (see Figs. 5 and 6). Besides, referring to the results of fatigue tests in which the initial stress was 50 per cent of the fatigue limit (Fig. 12), the effects of understressing and coaxing have not appeared in the ranges of the rate of stress increment tested here. Therefore the second assumption will be true except when the rate of stress increment is as small as that used for mild steel specimen No. 19.

This assumption, however, may not

be applicable for the case when the temperature of the testing material is held at over that of recrystallization since the accumulated energy is constantly diffused.

In the third assumption the change of state appearing in a specimen is prescribed according to the magnitude of repeated stress. Since the state of change of ability to dissipate energy in the course of fatigue has so far not been known, the fatigue mechanism has been defined indirectly with a coefficient of strain hardening, etc. (**5, 6**); in this study, however, the change of internal friction in the course of fatigue is applied directly, but the phenomena of variation of strain hardening and residual stress are considered to be involved incidently.

For the case when the fatigue strength is controlled by inherent notch effect on the surface or inside of the specimen, for the case of a progressive stress test for which a material having a remarkable property of strain aging is used, and for the case when the testing period extends over several days owing to the very small rate of stress increment, the assumptions described above will need proper modifications.

CONCLUSIONS

Fatigue tests under progressive stress have been carried out on metals—that is, the testing stress starting from zero being increased linearly with number of stress cycles up to rupture. Mild steel, duralumin, and brass have been tested under various rates of stress increment with the following results:

1. Approximately straight lines are obtained when the results of the progressive stress tests are plotted with the stress at failure as ordinate and the one-fourth power of the rate of stress increment as abscissa. The lines so obtained extrapolate very closely to the values of the fatigue limits determined by conventional methods.

2. The hypothesis is advanced that failure occurs under cyclic loading when the energy absorbed in each cycle in excess of a certain nondamaging amount accumulates to a critical total value. On the basis of this hypothesis, a theoretical relationship is developed between the stress at failure and the rate of stress increment that is in qualitative agreement with the experimental observation.

3. The relationship between the repeated stress and the number of stress cycles can be found by applying a similar idea (paragraph 2) to the case of an ordinary fatigue test; then *S-N* curves having tendencies the same as experimental curves can be obtained. From this result the inclination of the curve in the finite region and the physical meaning of the critical number of cycles in the *S-N* curve can be found.

4. Substituting constants in the equation of the *S-N* curve which have been determined from the experimental curve in Eq 6*a*, a relation between the stress at failure and the rate of stress increment generally agreeing qualitatively with the experimental one can be obtained. The process of fatigue failure in the ordinary fatigue test and in the fatigue test under progressive stress are, consequently, considered to follow an identical mechanism.

5. The fatigue test under progressive stress is considered to be effective as a quick method to determine the endurance limit.

Pending further experiments it will not be known if the above conclusions can be applied to materials so hard or brittle that inherent stress raisers on the surface or inside of them rule the fatigue failure or to materials susceptible to strain aging.

Acknowledgment:

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THE BEHAVIOR OF LONG HELICAL SPRINGS UNDER FLUCTUATING LOAD*

BY C. L. STAUGAITIS[1] AND H. C. BURNETT[2]

SYNOPSIS

A machine was constructed for testing long springs, operating on a guide rod, under fluctuating compressive loads. Results of tests on this machine showed that wear on the spring due to the guide rod reduced the life of the long springs far below that of short springs tested at the same stress range. Lubrication of the specimens increased their fatigue life considerably at relatively low stress ranges. The type of failure observed was influenced by the magnitude of the stress range in the test.

The National Bureau of Standards is engaged in a research program on the fatigue properties of music wire and springs, under the sponsorship of the Ordnance Corps, Springfield Armory. A previous report[3] presented the results obtained on this project in connection with a study of the relation between the bending fatigue properties of music wire and the fatigue properties of short[4] compression springs wound from the wire. Some of the data in the previous article are used for comparison in this report.

Machine design requirements frequently necessitate the use of long springs operating along a guide rod. This investigation was therefore undertaken to determine what, if any, effect a guide rod has on the fatigue life of long springs operating at high fluctuating stresses.

The terminology used in this paper is in accordance with the definitions as given in the ASTM Manual on Fatigue Testing.[5]

TEST METHODS AND MATERIALS

The fatigue machine used for this study was constructed at the National Bureau of Standards (Fig. 1). As many as four springs could be tested simultaneously, at a stress range determined by the design of the springs. A pneumatic sand rammer, *A*, which operated at about 10 strokes per sec was utilized as the driving mechanism. The specimens, *B*, were mounted on guide rods threaded into the movable collar plate, *C*, which

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[3] H. C. Burnett and C. L. Staugaitis, "Endurance of Helical Springs Related to Properties of the Wire," *Metal Progress*, Vol. 64, Sept., 1953, p. 77.

[4] A spring is classed as "short" if it can be compressed to solid height between parallel plates without buckling. "Long" compression springs must be guided.

[5] Manual on Fatigue Testing, Am. Soc. Testing Mats., 1949. (Issued as separate technical publication *ASTM STP No. 91*).

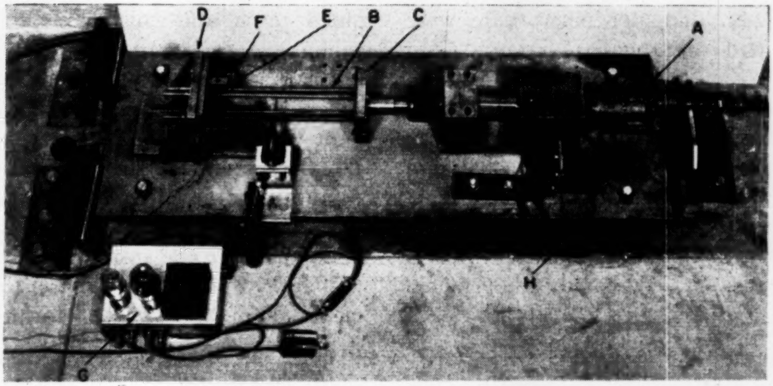

FIG. 1.—Machine for Testing Long Springs. *A*, pneumatic sand rammer; *B*, four springs operating on guide rods; *C*, collar plate on shaft of rammer; *D*, stationary bearing guide plate; *E*, washers; *F*, metal contacts; *G*, electronic relay; *H*, solenoid.

was fixed to the shaft of the rammer. The springs were compressed between this plate and the fixed plate, *D*, through which the guide rods were free to slide. The ends of the springs adjacent to the fixed plate were supported by hardened steel washers, *E*. Behind each washer there was a light compression spring which normally exerted less force on the washer than the test spring, even at maximum height. However, if the test spring broke or suffered a predetermined amount of loss in free height, the washer was pushed into contact with an adjustable stop, *F*. When such contact was made, an electronic relay, *G*, in conjunction with a solenoid operated air valve, *H*, stopped the machine.

Preliminary tests indicated that under certain conditions the excessive set that occurred during the test made it impossible to fracture the springs. Also, from a practical aspect, a spring is usually no longer serviceable if it loses more than a few per cent of its original free height or spring constant. Therefore, it was desirable to have some criterion of failure in addition to fracture.

In order to determine which of several possible criteria would be most satisfactory, fatigue tests on two long springs

TABLE I.—LONG SPRING (70 COILS) WOUND FROM 0.039-IN. DIAMETER WMA WIRE AND TESTED AT A NOMINAL STRESS RANGE OF 154,000 PSI.

Cycles	Set, per cent	Deflection Under Constant Load, in.	Number of Collapsed Coils	Remarks
0 000	0.0	3.10	..	
1 000	6.7	3.35	..	
2 000	7.6	3.30	..	
3 000	8.6	3.30	..	
4 000	8.6	3.30	..	
5 000	9.5	3.30	..	
6 000	10.0	3.30	..	
7 000	10.0	3.30	..	
8 000	10.0	3.30	1	
9 000	10.5	3.30	4	
10 000	10.5	3.30	4	
11 000	11.0	3.35	6	
12 000	11.0	3.45	8	
13 000	12.4	3.45	15	
14 000	13.3	3.45	18	
15 000	13.8	3.55	24	
16 000	15.2	3.40	29	
17 000	16.7	3.65	40	
18 000	17.1	3.60	40	
19 000	18.6	3.65	43	
20 000	19.1	3.80	47	
21 000	20.0	3.80	55	
22 000	20.5	3.80	60	
23 000	21.0	3.85	64	
24 000	21.5	3.85	64	
25 000	22.0	4.05	67	
26 000	23.8	3.95	68	
27 000	24.8	3.95	70	
28 000	25.7	3.95	70	
30 000	26.7	4.05	70	
35 000	29.0	4.10	70	
39 000	29.5	4.20	70	Fractured

of 0.039-in. diameter music wire were interrupted at regular intervals to measure the spring properties. Table I and Fig. 2 show the change in deflection under a fixed load, the loss in free height, and the number of collapsed coils[6] as a function of the number of cycles, for a spring tested at a stress range of 154,000 psi. From these data it was decided that the collapse of a coil could be considered as the point of failure in a spring.

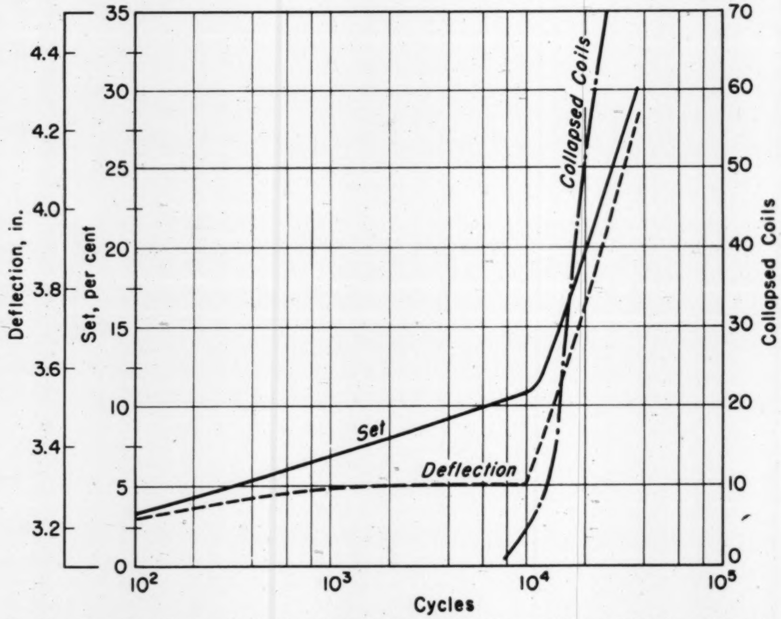

FIG. 2.—Results of a Test on a Long Spring (70 Coils) Wound From 0.039-in. Diameter WMA Wire and Tested at a Nominal Stress Range of 154,000 psi. Graph indicates per cent set (as measured by loss in free height), deflection under constant load, and number of collapsed coils at regular intervals of cycling.

Samples of 0.039-in. diameter music wire from two sources of supply (coded AMA and WMA) were tested. The mechanical properties of each are shown below:

	WMA	AMA
Tensile Strength	328 000 psi	368 000 psi
Torsional Yield Strength[7]	191 000 psi	216 000 psi

A Perkins precision spring coiler was used to coil the springs at a predetermined pitch and coil diameter. After coiling, the springs were stress relieved at 365 F for 25 min and then preset by compressing them several times to a point where the nominal shear stress in the outer fibers of the wire amounted to approximately 75 per cent of the tensile strength. Clearance between the guide rod and the inside of the spring was approximately 4 per cent of the inside diameter of the spring. The torsional shear stress range was computed from measurements of the pitch of the spring when in the maximum, minimum, and no load condition. Previous experience with short springs had indicated that small differences in minimum stress did not have a significant effect on fatigue life for a given stress

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[6] This was determined by compressing the spring and counting the number of points where adjacent turns were in contact.

[7] Torsional stress-strain curves were obtained by plotting nominal torsional shear stress against shear strain, γ. The torsional yield strength was defined as the stress at which the deviation of γ from the elastic line was 0.02.

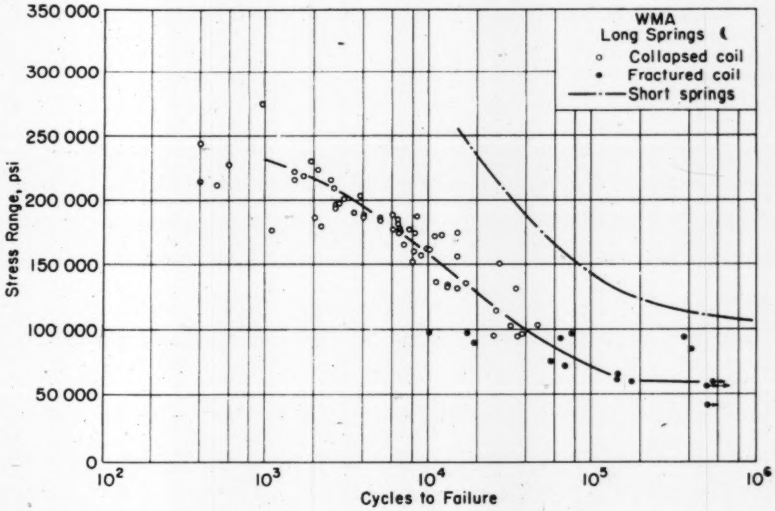


FIG. 3.—Results of Fatigue Tests of Long Springs Wound From WMA 0.039-in. Diameter Wire, and *S-N* Curve for Short Springs Wound From the Same Type Wire.[3]

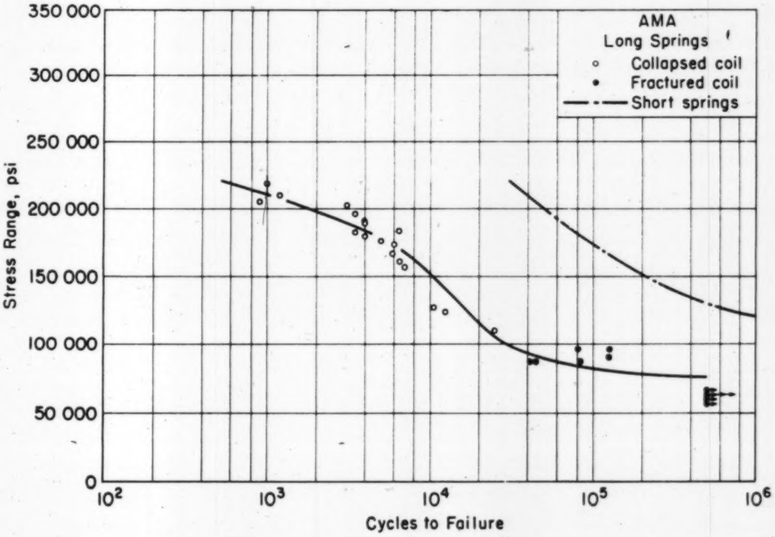


FIG. 4.—Results of Fatigue Tests of Long Springs Wound From AMA 0.039-in. Diameter Wire, and *S-N* Curve for Short Springs Wound From the Same Type Wire.[3]

range. Therefore no attempt was made to maintain a constant value of minimum stress, although it was usually about 15 per cent of the maximum.

RESULTS AND DISCUSSION

The results of fatigue tests on long compression springs are shown in Figs. 3 and 4; both graphs indicate that the fatigue life of long springs is considerably lower than that of short springs at corresponding levels of stress.

Examination of the long springs that were tested indicated that an important cause of the lower fatigue life was the wear on the inside of the spring where contact was made with the guide rod. All of the spring failures occurred in the first third of the spring length adjacent to the fixed head, where the rubbing action of the guide rod was at a maximum (Fig. 5).

There are two reasons why wear could cause a reduction in fatigue strength. First, the loss of material reduces the polar moment of inertia of the cross-section so that the applied load causes a higher stress. Second, the rubbing action can result in galling or fretting of the surface, with consequent formation of pits which can serve as nuclei for fatigue cracks. From the above it would be expected that the fatigue cracks would always start in the worn areas of the wire, and this was often, but not invariably, found to be the case. In Fig. 5, for example, there is a crack in the center coil running parallel to the length of the wire and located in the worn area. Cracks on longitudinal planes of weakness were frequently found after testing at relatively high stress levels, and they are believed to be responsible for the sharp decrease in the spring constant near the end of the test (Fig. 2).

The typical fracture appearance of springs tested in lower ranges of stress is shown in Fig. 6. Here again the effect of guide rod wear is clearly visible on the inside of the coil. However, the entire fatigue crack appears to be oriented normal to the tensile stress, and there were no discernible shear fatigue cracks under these test conditions.

Figure 7 shows an isolated case in which the fracture followed the plane normal to the length of the wire. The number of cycles to failure for this spring was within the normal range for this stress level.

To determine the effect of lubrication on the fatigue life of long springs, a series of additional tests was carried out on AMA 0.039-in. diameter music wire. Molybdenum disulfide, SAE No. 10 oil, and a suspension of molybdenum disulfide in No. 10 oil were used to lubricate the guide rods. Additional lubricant was applied to the guide rods and springs at intervals during the test. The springs were tested at stress ranges from 78,000 to 179,000 psi.

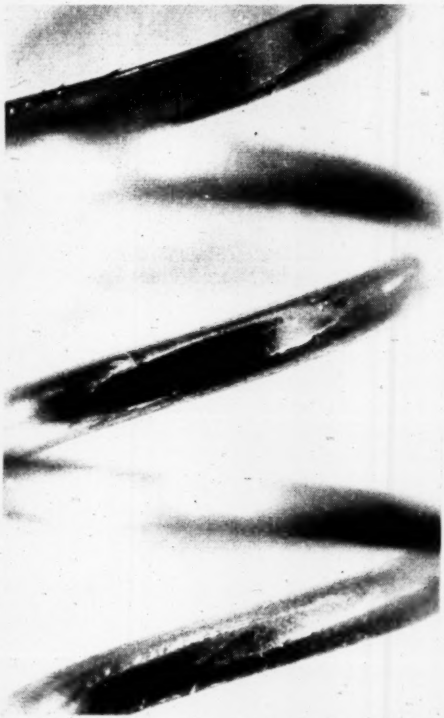


FIG. 5.—Portion of a Long Spring Showing Marked Degree of Guide Rod Wear on Inside Surfaces. The middle coil also contains a fatigue crack running parallel to the wire (×15, reduced ½ in reproduction).

A comparison of the limited test results recorded in Table II with those given in Fig. 4 indicates that lubrication with dry molybdenum disulfide may

TABLE II.—LONG SPRINGS MADE FROM AMA 0.039-IN. DIAMETER WIRE.

Stress Range, psi	Cycles to Close Coil	Cycles to Fracture Coil	Lubricant
179 000	5 400		Molybdenum Disulfide
178 100	5 400		Molybdenum Disulfide
176 400	3 800	40 000	Molybdenum Disulfide
132 000	41 000	85 000	Molybdenum Disulfide
128 000	42 000	45 000	Molybdenum Disulfide
127 600	50 000	76 000	Molybdenum Disulfide
88 700	177 000	283 000	Molybdenum Disulfide
78 400	400 000	700 000[a]	Molybdenum Disulfide
86 100	83 000	93 000	Molybdenum Disulfide + No. 10 oil
79 000	110 000	130 000	No. 10 oil

[a] Spring did not break.

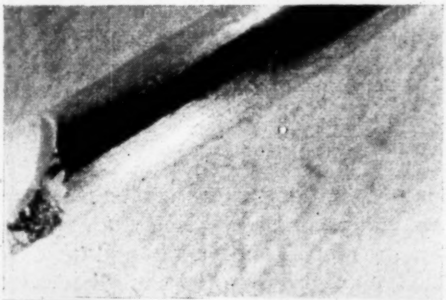
more than double the fatigue life of the springs for stress levels below 150,000 pounds psi. At the higher levels of stress, little improvement was noted.

SUMMARY AND CONCLUSIONS

Results of fatigue tests on long compression springs made from two lots of music spring wire appeared to justify the following conclusions:

1. In tests at high stress ranges, the excessive loss in free height frequently made it impossible to fracture the springs. It was determined that the collapse of a coil under a given static load served as a satisfactory criterion of failure under these circumstances.
2. The fatigue life of long springs operating on a guide rod was considerably shorter than that of short springs at corresponding stress ranges. Examination of the tested springs indicated that an important cause for the marked difference in fatigue strength between long and short springs was the wear due to the guide rod on which the long springs operated.
3. Lubrication with dry molybdenum disulfide improved the fatigue life of long springs operating at stress ranges below 150,000 psi.
4. In springs tested at relatively high stress ranges, the initial fatigue crack apparently developed on planes of weakness parallel to the length of the wire. These cracks frequently propagated along a considerable length of the wire and resulted in a marked loss of stiffness before fracture. At relatively low stress ranges the initial crack usually appeared to be on a plane at 45 deg to the axis—that is normal to the tensile stress.

FIG. 6.—Typical Fracture of a Spring Wound From 0.039-in. Diameter Music Wire Tested at a Stress Range of 60,800 psi (×25) (reduced ½ in reproduction).



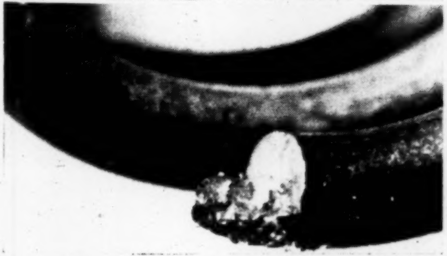


FIG. 7.—Fracture of a Spring Tested at a Stress Range of 152,700 psi. This was an isolated case of failure along a plane transverse to the axis of the wire (×25, reduced ½ in reproduction).

ANISOTROPY OF FATIGUE STRENGTH OF A STEEL AND TWO ALUMINUM ALLOYS IN BENDING AND IN TORSION*

By W. N. Findley[1] and P. N. Mathur[2]

Synopsis

An investigation of anisotropy in fatigue, under two different states of stress, bending and torsion, was made of two aluminum alloys and a steel. A somewhat similar variation of the fatigue strengths with orientation relative to the texture was observed for all three metals. The fatigue strength in bending decreased as the orientation changed from longitudinal to diagonal to transverse; and the fatigue strength in torsion was nearly constant at all three orientations.

The results of the tests may be explained by the concept that cyclic principal shear stress is primarily the cause of fatigue; but the ability of the anisotropic materials to withstand this action of cyclic shear stress is influenced by the magnitude and the direction of the complementary normal stress acting on planes of principal shear stress, as well as by the anisotropic texture of the material.

Since the anisotropy was observed to be different for the two states of stress, bending and torsion, the combined stress theories of fatigue failure, based on linear superposition of the stress fields in bending and torsion, warrant a correction for anisotropy.

The importance of anisotropy as a factor influencing the fatigue strength of metals under combined stress has been recognized in previous papers (**1, 2, 3**)[3] on combined stress fatigue, but data have not been available. The present tests for anisotropy were undertaken to provide such data.

To properly interpret the laboratory data on fatigue under combined stress an understanding of anisotropy of the fatigue properties of metals and the relation of anisotropy to the impressed state of stress is desirable. A knowledge of directional properties of the material is also required in the design of many machine parts subjected to maximum stresses that are not necessarily in the direction of maximum strength of the material.

Previous Work:

Most fatigue studies for anisotropy reported in previous literature on the subject have been concerned with fatigue tests made in bending on specimens cut

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[3] The boldface numbers in parentheses refer to the list of references appended to this paper, see p. 937.

TABLE I.—REDUCTION IN FATIGUE STRENGTH FROM LONGITUDINAL TO TRANSVERSE ORIENTATION.

Metal	Reduction, per cent	Reference[a]	Remarks
Ni-Steel	21.3	J. Pomey (**16**)	
Ni-Steel	45.0		
Cr-Steel	13.1		
Cr-Steel	16.65		
Cr-Mo Steel	26.8		
Ni-Cr Steel	40.0		
Ni-Cr Steel	15.7		
Ni-Cr Steel	37.3	Pomey and Ancella (**8, 16**)	Solid specimens
Ni-Cr Steel	1.6		Notched specimens
Steel	4.5	M. Perrin (**16**)	Location: surface
Steel	14.5		Between surface and center
Steel	17.5		Center
Ni-Cr-Mo Steel	30.0	Von Rossing (**19**)	Location: surface
Ni-Cr-Mo Steel	17.0		Center
Cr-Mo-Steel	8.0		Surface
Cr-Mo-Steel	2.5		Center
Ni-Cr-Mo Steel	17.7	M. Lioret (**16**)	
Steel	15.0	Schmidt (**17**)	
Steel	7.0		
Steel	11.4		
Steel	28.5		
Cr-Ni Steel	13.3	R. Mailander (**10**)	
Cr-Ni Steel	21.0		
Cr-Ni Steel	22.0		
Ni Steel	23.8	A. Junger (**9**)	
Duralumin	20.0	Berner and Kostron (**11**)	
SAE 4340 Steel	32.0	Ransom and Mehl (**4, 5**)	
Guntube Steels	16.0		
SAE 4340 Steel	48.0	Ransom (**6**)	
Steel Forging	30.0		
14S-T, 24S-T aluminum alloys	30,35	Marin (**12**)	

[a] The boldface numbers in parentheses refer to the list of references appended to this paper, see p. 937.

parallel and perpendicular to the direction of the grain of the stock. The anisotropy was indicated by the comparative fatigue strengths (or per cent variation) in the two directions.

A survey of the results of these fatigue investigations indicates a varying degree of anisotropy in different steels and aluminum alloys (Table I). A very high degree of anisotropy was observed in several studies on SAE 4340 steel forgings (**4, 5, 6**), on heat treated steels (**7**), and on different nickel and nickel-chromium steels (**8, 9, 10**). Fatigue tests of aluminum alloys in some studies (**11, 12**) indicate high anisotropy while other investigators (**13, 14, 15**) studying different steels and aluminum alloys reported very little or no evidence of anisotropy.

Tests of similar nature disclosed the influence on the anisotropy of variables such as the degree of forging reduction (**16, 17, 18**), location of the forged piece in the billet (**16**), stress gradient (notches) (**16**), etc. To the knowledge of the authors, fatigue tests for anisotropy in torsion have been reported in only two instances. Von Rossing (**19**) reported results of fatigue tests on chromium-molybdenum and nickel-chromium-molybdenum steel forgings. His data indicated little or no anisotropy in torsional fatigue, but rather pronounced anisotropy in bending fatigue. Recently, Ransom (**6**) reported results of torsion and bending fatigue tests for anisotropy of SAE 4340 steel forgings. He observed that most cracks initiated at inclusions for all orientations in torsion and for only transverse orientations in bending.

The literature on anisotropy of the static properties of metals has been reviewed in detail by Barrett (**20**).

The present study was begun in September 1950 to investigate the influence of anisotropy on fatigue properties under two different states of stress for three materials used in an investigation of fatigue of metals under combined bending and torsion (**1, 2, 3, 21, 22, 23, 24**).

MATERIALS, SPECIMENS AND TEST PROCEDURE

Materials:

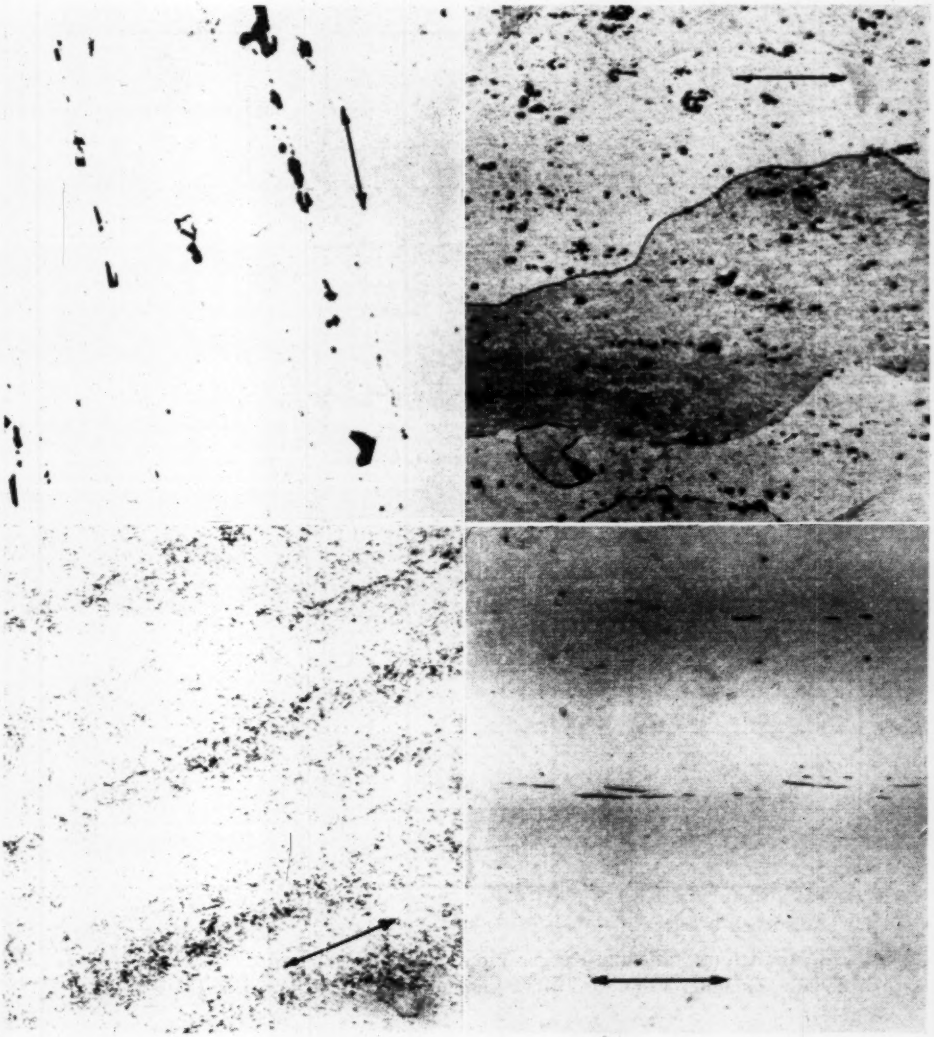
The investigations for anisotropy covered SAE 4340 steel, Rockwell hardness C scale, 25, and 25S-T6 and 76S-T61 aluminum alloys. Fatigue tests on these metals were conducted both in bending and torsion on miniature specimens, having their axes in longitudinal, diagonal, and transverse directions relative to the axes of the 1-in. hot rolled bars from which they were prepared. Details of composition and heat treatment are given for the first two materials in references (**24**) and (**2**), respectively except that the steel specimens in the present tests were drawn at 1250 F to produce the hardness indicated. The 76S-T61 aluminum had the following composition (per cent): 7.6 zinc, 1.6 magnesium, 0.6 copper, 0.5 manganese, 0.5 iron, 0.25 silicon, 0.1 titanium. One inch square bars of 76S-T61 aluminum were swaged to 1-in. round, then heated for 10 hr at 860 F, quenched in water and aged for 12 hr at 275 F.

Preparation of Specimens:

All fatigue specimens were of the miniature type, as shown in Fig. 5 of reference (**25**), $\frac{3}{4}$ in. long and with a $\frac{3}{32}$-in. minimum diameter and a $\frac{3}{16}$-in. radius. These specimens had a Neuber stress concentration factor in bending of 1.09 and in torsion of 1.04. All specimens were polished dry with Nos. 1, 00, and 0000 carborundum paper wound around a $\frac{1}{4}$-in. diameter rotating spindle. All static tension specimens were prepared in the laboratory of the Aluminum Company of America in the manner described in reference (**26**).

The fatigue specimens of 76S-T61 aluminum alloy were cut from several rectangular blocks machined from the round bars. The orientations of the specimens were recorded, and specimens were tested in sets, insofar as possible, so that at each stress a longitudinal, diagonal, and transverse specimen were tested from the same block. The static tension specimens were prepared with the same orientations from parts of larger fatigue specimens which had previously been tested.

Fatigue specimens of 25S-T6 aluminum alloy were cut from one continuous bar because it had been observed in tension tests of this material that the surface roughened during yielding, with an uneven "grain" size varying from small to large in alternate quadrants.



(*a*) 76S-T61 Aluminum Alloy (×250).

(*b*) 25S-T6 Aluminum Alloy (×250).

(*c*) SAE 4340 Steel (×250).

(*d*) SAE 4340 Steel, Unetched (×250).

Fig. 1.—Photomicrographs Showing the Texture of Metals Parallel to the Axis of the Rolled Bars.

Metallurgical examination and hardness measurements also indicated a variable grain size. All but six of the fatigue specimens with longitudinal, diagonal, and transverse orientations, were prepared from two slabs cut as close to the center of the bar as possible and parallel to the diameter of greatest hardness. The other six specimens were oriented transverse to the bar and perpendicular to the slab.

Unfortunately this procedure was not

followed in the static tension specimens of 25S-T6 aluminum alloy. These specimens were machined from short ends of bars, consequently the radial orientation of the specimens was not known.

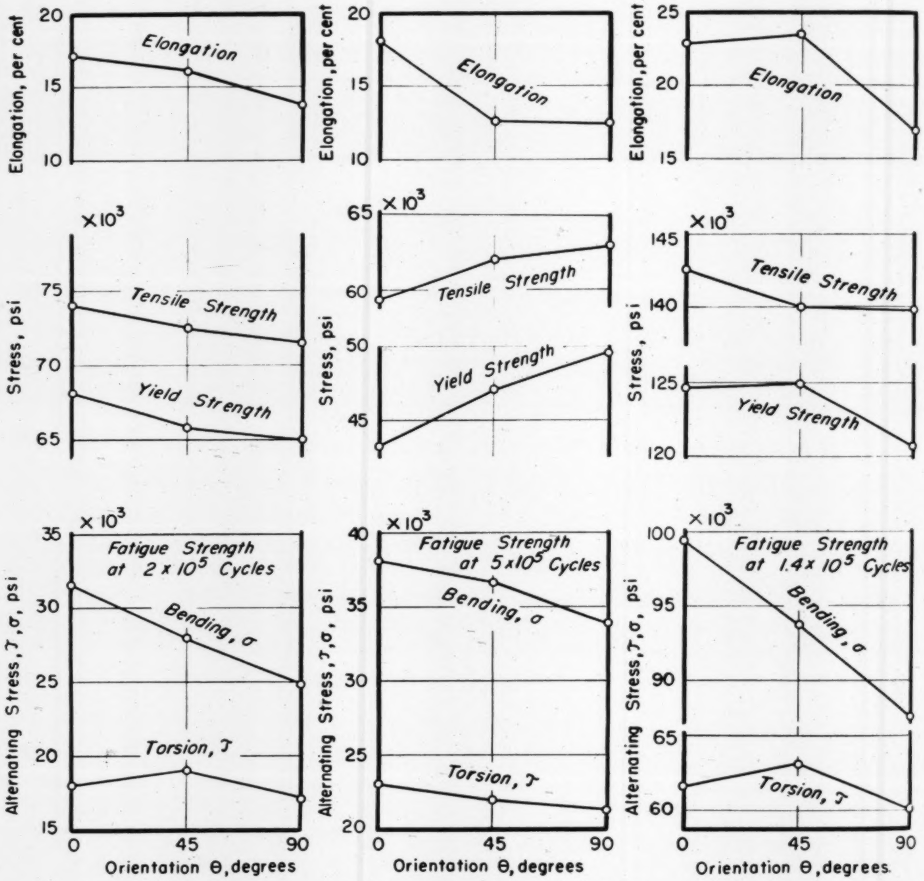


FIG. 2.—Variation of Static and Fatigue Properties With Orientation θ Relative to Texture (*a*) 76S-T61 Aluminum Alloy. (*b*) 25S-T6 Aluminum Alloy. (*c*) SAE 4340 Steel, R_c 25.

Fatigue and static tension specimens of SAE 4340 steel were prepared in the same manner as the 25S-T6 aluminum specimens, except that the fatigue specimens were machined from several short ends of bars selected for uniform hardness. The radial orientation was not controlled.

Static Tests:

The static tests on these materials were made at the Aluminum Research Laboratories of the Aluminum Company of America using special equipment for static tension tests of miniature specimens (**26**, **27**). For each material, duplicate tension tests were made on 0.05-in. diameter specimens, having longitudinal, diagonal, and transverse orientations. The details of these tests are described in a report by Babilon (**28**).

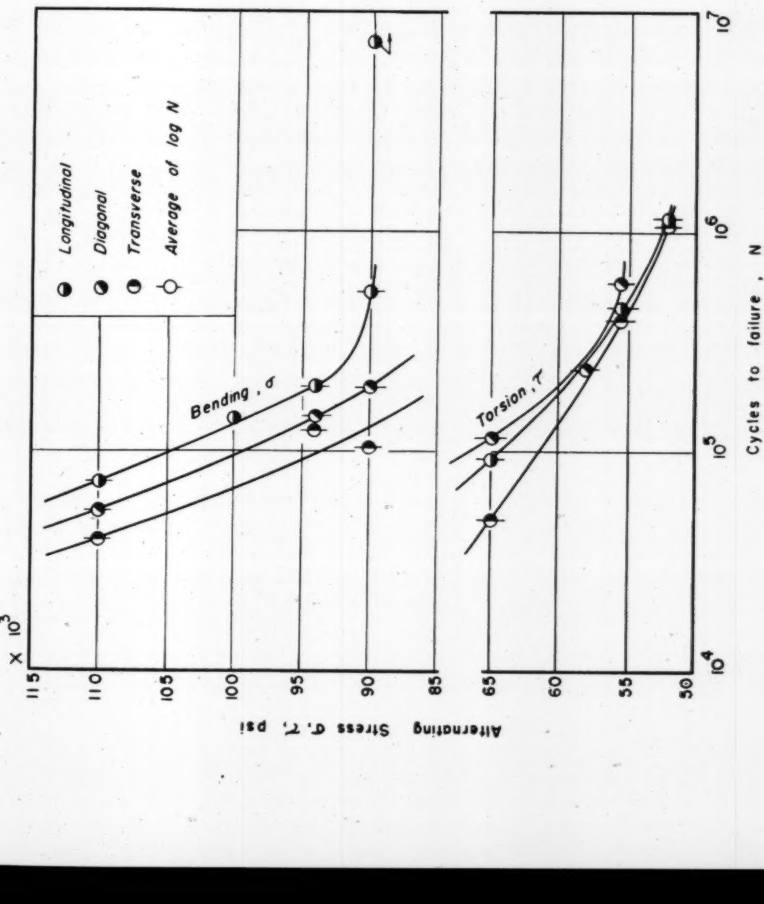


FIG. 3.—Fatigue Tests of SAE 4340 Steel, R_c 25.

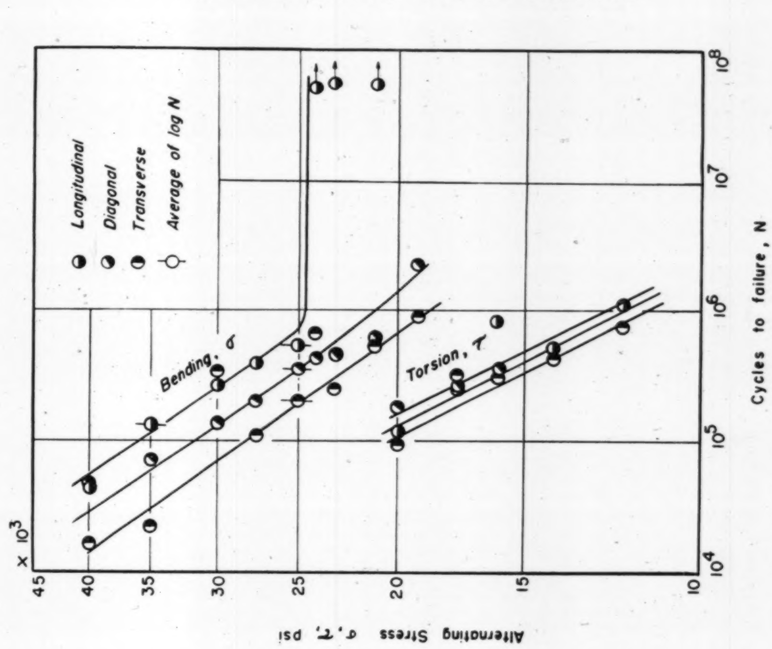


FIG. 4.—Fatigue Tests of 76S-T61 Aluminum Alloy.

Metallurgical Examination:

The photomicrographs shown in Fig. 1 of the longitudinal sections near the center of the bars revealed the following:

25S-T6 Aluminum Alloy.—This alloy had a uniform distribution of fragmented aluminum-copper-iron-manganese inclusions and a few copper-aluminum globules in the direction of working. The inclusion content of this alloy was high.

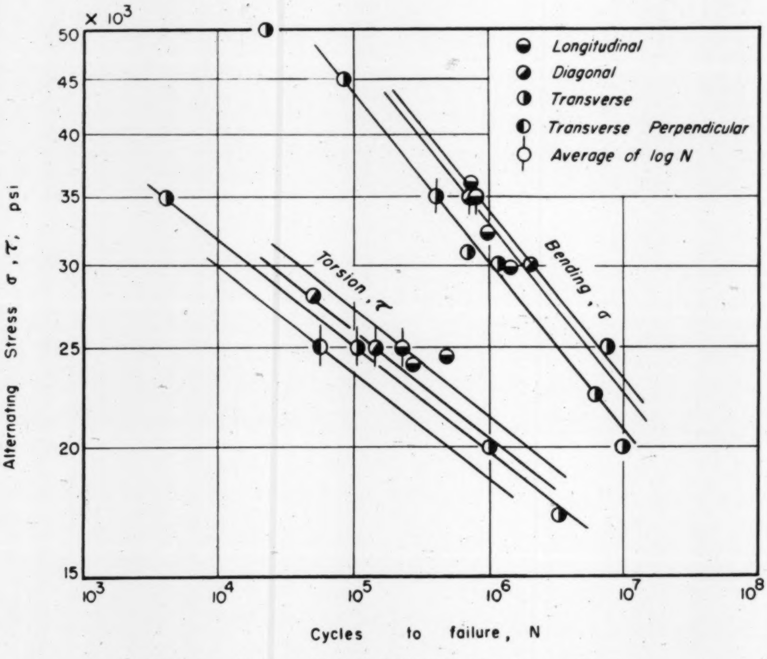


FIG. 5.—Fatigue Tests of 25S-T6 Aluminum Alloy.

76S-T61 Aluminum Alloy.—There were fewer inclusions than in the 25S-T6 alloy, mostly of aluminum-copper-iron and aluminum-copper-iron-manganese, forming an inclusion texture in the direction of working.

SAE 4340 Steel.—The structure had a highly banded distribution of carbides in the direction of rolling. Photomicrographs of an unetched surface revealed elongated plastic inclusions, less than $\frac{1}{4}$-in. long at a magnification of 250×, aligned along the same direction.

Fatigue Tests:

The fatigue tests were conducted in constant amplitude-of-deflection type Krouse fatigue machines modified by a specially designed fixture (**25**). The details of the specimens, the fixture, the method of loading specimens in bending and torsion, and the test procedure have been described in an earlier paper (**25**). Because the geometry of crack formation frequently permitted the machine to continue running after the specimen had fractured, specimens in torsion were inspected with a magnifying glass every 10 min to detect cracks. For bending tests a slight tension load applied by a flexible coil spring solved the problem.

The diameter of each specimen was measured by means of a shadowgraph. For bending, the diameter was measured in the plane of bending; for torsion specimens, this diameter was averaged with the diameter at right angles to it.

The procedure for determining the

TABLE II.—FATIGUE DATA FOR ANISOTROPY OF SAE 4340 STEEL, ROCKWELL C 25 (*SERIES B*).

State of Stress	Stress, psi	Specimen	Cycles to Failure	Stress, psi	Specimen	Cycles to Failure	Stress, psi	Specimen	Cycles to Failure
				LONGITUDINAL ORIENTATION					
Bending..........	110 000	1	65 000	94 000	1	228 000	90 000	1	744 000
		2	57 000		2	184 000		2	526 000
		3	98 000		3	288 000		3	237 000
					4	197 000		4	817 000
					5	129 000			
Average log N......			4.8533			5.2974			5.7199
Torsion............	65 000	1	56 000	55 400	1	368 000	52 000	1	352 000
		2	79 000		2	250 000		2	2 014 000
		3	172 000		3	325 000		3	1 473 000
					4	386 000		4	329 000
					5	822 000		5	3 103 000
Average log N......			4.9604			5.5954			6.0056
				DIAGONAL ORIENTATION					
Bending..........	110 000	1	50 000	94 000	1	157 000	90 000	1	198 000
		2	55 000		2	104 000		2	254 000
		3	47 000		3	264 000		3	192 000
		4	56 000		4	121 000		4	164 000
		5	52 000					5	177 000
Average log N......			4.7151			5.1793			5.2895
Torsion............	65 000	1	110 000	58 000	1	214 000	55 400	1	498 000
		2	125 000		2	425 000		2	755 000
		3	78 000		3	333 000		3	519 000
		4	69 000		4	157 000			
		5	288 000		5	152 000			
Average log N......			5.0657			5.3718			5.7634
				TRANSVERSE ORIENTATION					
Bending..........	110 000	1	50 000	94 000	1	127 000	90 000	1	124 000
		2	28 000		2	127 000		2	107 000
		3	42 000		3	110 000		3	85 000
		4	33 000		4	175 000		4	86 000
		5	45 000		5	97 000		5	118 000
Average log N......			4.5899			5.0958			5.0117
Torsion............	65 000	1	30 000	55 400	1	742 000	52 000	1	616 000
		2	54 000		2	262 000		2	1 978 000
		3	48 000		3	264 000		3	733 000
		4	42 000		4	676 000		4	1 394 000
		5	85 000		5	480 000		5	848 000
Average log N......			4.6887			5.6443			6.0047

S-N diagrams of each material in bending and torsion at each orientation consisted in tests of series *A* and *B* as follows:

Series A.—Tests were made of one or two specimens at each orientation at various stresses to determine the shape of the *S-N* curve.

Series B.—Tests of several specimens at each orientation were made at one stress to determine a more definite value of the fatigue strength.

TEST RESULTS

Static Tests:

The results of tension tests for anisotropy of all three metals are presented in

Fig. 2. The diagrams represent the variation in the mechanical properties with orientation θ relative to the texture (or axis of the parent bar). The details of the test results are described in a report by Babilon (**28**).

Fatigue Tests:

The data obtained from the fatigue tests described in the preceding sections are presented in the form of *S-N* diagrams in Figs. 3, 4, and 5. Data obtained from series *B* tests are summarized in Tables II and III. The data points in the *S-N* diagrams represent the individual specimens of series *A* as well as the alternating stress *versus* the average log *N* of *n* specimens of series *B* (Tables II and III).

TABLE III.—FATIGUE TESTS FOR ANISOTROPY OF 25S-T6 ALUMINUM ALLOY (*SERIES B*).

State of Stress	Stress, psi	Orientation							
		Longitudinal		Diagonal		Transverse		Transverse Perpendicular	
		Specimen	Cycles to Failure, *N*	Specimen	Cycles to Failure, *N*	Specimen	Cycles to Failure, *N*	Specimen	Cycles to Failure, *N*
Bending	35 000	1	1 070 000	1	1 007 000	1	804 000		
		2	1 240 000	2	529 000	2	296 000		
		3	738 000	3	552 000	3	458 000		
		4	591 000	4	926 000	4	143 000		
		5	751 000	5	716 000	5	566 000		
		6	364 000	6	668 000	6	427 000		
		7	1 237 000	7	677 000	7	445 000		
Average log *N*			5.9036		5.8493		5.6035		
Torsion	25 000	1	127 000	1	142 000	1	113 000	1	14 000
		2	73 000	2	141 000	2	180 000	2	75 000
		3	234 000	3	223 000	3	117 000	3	51 000
		4	477 000	4	150 000	4	71 000	4	45 000
		5	467 000	5	104 000	5	75 000	5	106 000
		6	224 000	6	222 000	6	114 000	6	92 000
		7	259 000	7	69 000				
Average log *N*			5.3495		5.1469		5.0266		4.7285

The fatigue strengths in bending and torsion interpolated from the *S-N* curves at a given number of cycles, together with the static properties, are presented in Fig. 2 as a function of the orientation θ relative to the texture. For all three metals, the fatigue strength in bending decreased from longitudinal to diagonal to transverse orientation, with the diagonal value nearly intermediate between the other two.

The fatigue strength in torsion did not change so much as in bending. It was highest in the diagonal direction for two of the metals and highest in the longitudinal direction for 25S-T6 aluminum. In all three materials the fatigue strength in torsion of transverse specimens was lowest.

While the data points in Fig. 2 are connected by straight lines for clarity of presentation, it is recognized that curves are more likely relations, since the diagrams represent only one quadrant in a repeating pattern duplicated directly or inversely in other quadrants; and also abrupt changes in the relations with orientation are not likely.

There seems to be rather strong evidence that an endurance limit existed in the 76S-T61 aluminum alloy in bending, as shown in Fig. 4. The only other evidence (**29**) known to the authors of an endurance limit in aluminum alloys indicated that an endurance limit for

75S-T6 was reached at about 10^8 cycles. In the present tests the endurance limit was reached at about 10^6 cycles.

The variations of the static and fatigue properties in the transverse direction expressed in percentage of the longitudinal values were as follows:

76S-T61 aluminum alloy: Bending fatigue strength, −17.0 per cent; torsion fatigue strength, −4.4 per cent; tensile strength, −3.2 per cent; yield strength, −4.7 per cent; and percentage elongation, −19.8 per cent.

25S-T6 aluminum alloy: Bending fatigue strength, −11.0 per cent; torsion fatigue strength, −7.4 per cent; tensile strength, +5.9 per cent; yield strength, +14.5 per cent; and percentage elongation, −31.3 per cent.

SAE 4340 Steel: Bending fatigue strength, −12.0 per cent; fatigue strength in torsion, −2.9 per cent; tensile strength, −2.0 per cent; yield strength, −3.2 per cent; and percentage elongation, −25.4 per cent.

The fatigue strength of 25S-T6 aluminum alloy in torsion for transverse specimens perpendicular to the plane of greatest strength (designated as the transverse-perpendicular orientation) was found to be about 6.6 per cent less than the corresponding value in the plane of greatest strength.

In torsion tests of miniature specimens of the 25S-T6 aluminum alloy, it was observed that the initial crack propagation appeared to be along longitudinal planes of the longitudinal specimens and along transverse planes of the transverse specimens. This indicates a lower resistance to fatigue fracture in shear along planes containing the direction of the texture.

The fact that the tensile strength data for 25S-T6 aluminum alloy were higher in the transverse orientation than in the longitudinal is difficult to explain. It may result from variations in tensile strength along different diameters in the bar as observed for fatigue strength.

In view of the different trends for bending and torsion fatigue strengths, it would be of interest to also have static torsion test data to determine whether the strength in torsion is greatest in specimens oriented at 45 deg.

Size Effect:

A comparison of the results of the present tests of longitudinal specimens in bending and torsion may be made with previous tests (**1, 2, 21**) of the same materials with larger diameter specimens —0.26-in. diameter for 76S-T61 aluminum alloy and SAE 4340 steel and 0.30-in. diameter for 25S-T6 aluminum alloy.

The present tests of $\frac{3}{32}$-in. diameter specimens show both higher and lower fatigue strengths than the larger specimens; the fatigue strength of the smaller diameter specimen of 76S-T61 aluminum alloy at 2×10^5 cycles was 16 and 27 per cent lower in bending and torsion respectively; the fatigue strength of 25S-T6 aluminum alloy at 5×10^5 cycles was 9 and 11 per cent higher in bending and torsion respectively; and the fatigue strength of SAE 4340 steel at 1.5×10^5 cycles was 23 and 14 per cent higher in bending and torsion respectively.

The reasons for these differences are not apparent. The testing techniques for both tests of 76S-T61 aluminum alloy were the same, and the technique employed for the larger specimens of the other two materials was not significantly different from that used in the present tests. The miniature specimens were taken as nearly as possible from the same position in the bar as the larger specimens, but the test section was as much as $\frac{1}{8}$-in. farther from the center of the bar.

Ratio of Fatigue Strengths in Bending and Torsion:

Most theories of failure which have been considered for describing fatigue failure under combined stress require a constant value for the ratio of the fatigue strength in bending to that in torsion, see Table II of reference (22). Examination of the data for the three metals considered in the present report discloses the following values of the ratios of the fatigue strength in bending *b* to that in torsion *t*:

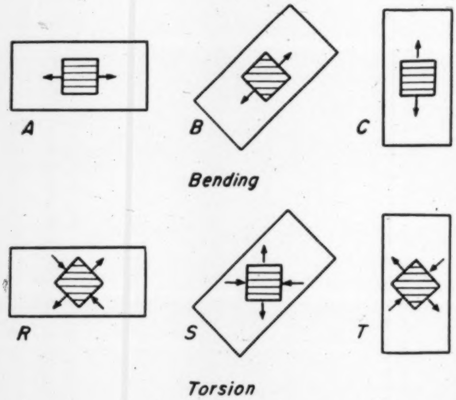


FIG. 6.—Orientation of Principal Stresses Relative to the Texture of the Material in Tests for Anisotropy in the Fatigue Properties. (The direction of the texture is horizontal.)

The values of *b/t* for the larger specimens and for the longitudinal, diagonal, and transverse miniature specimens are respectively:

76S-T61 aluminum alloy	1.53, 1.75, 1.46, 1.43
25S-T6 aluminum alloy	1.67, 1.64, 1.65, 1.63
SAE 4340 steel	1.61, 1.60, 1.49, 1.46

These values are very consistent for 25S-T6 aluminum alloy, show considerable difference between materials, and indicate the highest value for miniature specimens of longitudinal orientation in one of the materials.

ANALYSIS AND INTERPRETATION OF RESULTS

The states of stress, bending, and torsion, when applied to the three orientations, longitudinal, diagonal, and transverse, may be considered as representing six different states of stress on an element of anisotropic material. The fatigue data have been interpreted with the help of diagrams representing these elements in Figs. 6 and 7.

Principal Stress Theory:

Figure 6 shows the relationship between the direction of the principal stresses and the texture of the material (shown by the horizontal lines). If the greatest principal stress were the important factor in causing fatigue, the following should be observed: (1) the fatigue strength in bending should decrease from longitudinal *A* to diagonal *B* to transverse *C* as observed in Fig. 2; (2) the fatigue strength in torsion should be the same in longitudinal *R* and transverse *T* specimens (this was nearly the case for two of the materials); (3) the ratio *B/C* of the fatigue strengths in bending for diagonal specimens to that for transverse specimens should be the same as the ratios R/S or T/S of the fatigue strengths in torsion for longitudinal or transverse specimens to that for diagonal specimens. This was not observed except for R/S in 25S-T6 aluminum alloy. Instead $B/C > 1$, while $R/S = T/S < 1$. Therefore, the greatest principal stress cannot be the stress factor which causes fatigue in these materials.

Principal Shear Stress Theory:

In Fig. 7 the relationships between the directions of the principal shear stresses and the texture of the material are shown. If the principal shear stresses were responsible for initiating fatigue failure the following should be observed: (1) the fatigue strength in torsion should be the same in the longitudinal R and transverse T specimens (nearly the case for two of the materials); (2) the fatigue strength of the diagonal specimen in bending B, expressed in terms of shearing stress, should be the same as that of the torsion specimens R and T (this was not the case); (3) the fatigue strength in bending should be the same for longitudinal A and transverse C specimens (this was not observed); and (4) the fatigue strength in bending for specimens A and C, expressed as shearing stress, should equal the fatigue strength in torsion of the diagonal specimens, S (this also was not observed).

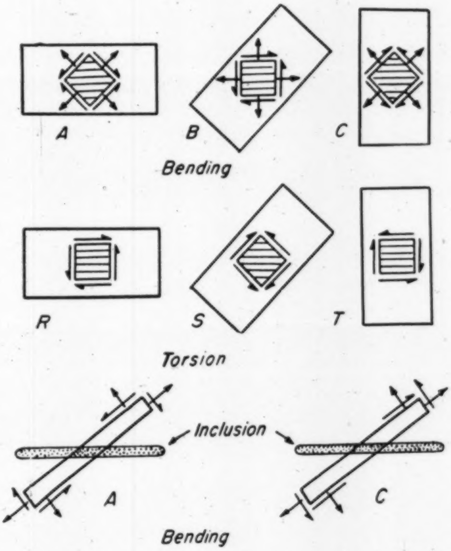


FIG. 7.—Orientation of Principal Shear and Complimentary Normal Stresses Relative to the Texture of the Material in Tests for Anisotropy in the Fatigue Properties. (The direction of the texture is horizontal.)

Principal Shear Stress plus Complementary Normal Stress Theory:

In Fig. 7 the normal stresses acting on planes of principal shear stress, here called "complementary normal stresses," are also shown. If the factor primarily responsible for fatigue were cyclic shear stress and if the ability of the material to withstand the action of the cyclic shear stress were influenced by the magnitude and sign of the complementary normal stress, the following should be observed: (1) the fatigue strengths in torsion, *R* and *T*, should be the same (nearly the case for two of the materials); (2) the fatigue strength in bending, expressed as shearing stress, for the diagonal specimen, *B*, should be less than the fatigue strengths, *R* and *T*, in torsion (this was observed); (3) the fatigue strengths in bending, expressed as shearing stress for specimens *A* and *C* should be less than the fatigue strength of the diagonal specimens, *S*, in torsion (this was observed). The fact that the longitudinal fatigue strength is greater than the transverse may be explained by the aid of the two lowest diagrams in Fig. 7. For example, in the longitudinal specimens the complementary normal stress would tend to open a crack between the metal and an inclusion, while the principal shear stress would tend to close the crack. But, in the transverse specimen both complementary normal stress and principal shear stress tend to open a crack. Thus it would be expected that the transverse specimen would be weaker.

The above analysis suggests that the principal stress and principal shear stress theories are not applicable, but that the theory of the principal shear stress plus the complementary normal stress may be applicable to fatigue.

INFLUENCE OF ANISOTROPY ON COMBINED STRESS FATIGUE

The results of the tests on all three materials indicate that the influence of anisotropy on fatigue strength is considerably different for the two states of stress, bending and torsion. The fatigue strength of these metals under combined bending and torsion will then be influenced by anisotropy. Its effect will depend on the relative magnitudes of the bending and torsional components of stress. A theory predicting the fatigue strength of metals under combinations of two different states of stress cannot be based therefore on the linear superposition of the two stress fields without accounting for anisotropy.

In discussion of a previous paper (**30**), a method of correcting theories of failure for anisotropy was proposed and applied to data on fatigue for the special case of combined bending and torsion (**1, 2, 3**). Now that data on anisotropy of these same materials are available, it is proposed for a later time to reexamine the correction for anisotropy and the relations between theories of failure and the available test data.

CONCLUSIONS

1. The influence of anisotropy on the fatigue strength of metals is not independent of the state of stress in bending and torsion. Consequently, the classical theories for combined stress fatigue based on linear superposition of stress fields in bending and torsion warrant a correction for anisotropy.

2. The results of fatigue tests may be explained by the concept that the cyclic principal shear stress is primarily responsible for fatigue, but the ability of anisotropic materials to withstand the action of cyclic shear stress is influenced by the magnitude and sign of the complementary normal stress.

Acknowledgment:

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The authors are greatly indebted to D. M. Sen, D. R. Burnett, W. F. Wendt, D. D. Strohbeck, and W. A. Hagemeyer for performing tests and assisting in the analysis of test data, and to R. W. Bohl for the metallurgical analysis and photomicrographs.

The cooperation of R. L. Templin, F. M. Howell, and C. F. Babilon of the Aluminum Company of America in performing static tension tests of miniature specimens for this project is gratefully acknowledged.

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DISCUSSION

Mr. J. A. Bennett[1] (*presented in written form*) — The authors have presented some very interesting and thought-provoking data. From what we know about the way in which fatigue cracks initiate, it is difficult for me to relinquish the concept that the maximum resolved shear stress is the controlling factor in fatigue, and I have a suggestion or two that might permit us to retain such a conception even in the face of this apparently contradictory data.

I believe that there are two distinct causes for the variation of fatigue properties with direction: first, the variation in effective stress concentration about elongated inclusions or other built-in stress-raisers and, second, the actual difference in properties of the metal in which the inclusions are embedded. If we accept the idea that fatigue is caused primarily by shear stress, then differences of the second kind would not be shown by the comparison of longitudinal bending and transverse bending specimens because the planes of maximum shear stress are at 45 deg to the texture in both cases. As the 45-deg bending specimens gave results nearly midway between those of the longitudinal and transverse specimens, we can reasonably conclude that in the materials used by the authors the primary effect of direction on fatigue was due to stress concentrations. This effect was not important in torsion because stress-raisers are not as effective under pure shear stress.

On this basis the principal difference to be explained is that between the torsion and bending results. If we consider the fatigue strength in terms of the maximum shear stress and compare cases where the shear stress direction relative to the texture is the same, the ratio of torsion to bending fatigue strength is 1.2 to 1.3. Many of the results reported by Gough[2] were in this same range.

At a point in the surface of a metal subjected to uniaxial stress, the normals to the planes of maximum shear stress make an angle of 45 deg with the stress direction, so the locus of these normals is a cone. Under pure shear conditions, however, there are only two planes of maximum shear stress through a given point on the surface, so the locus of the normals is a pair of lines rather than a cone. Fatigue failure will presumably start in the individual crystal having the highest resolved shear stress. I wonder if the higher strength in torsion might be due merely to the fact that under this type of loading there is less chance of a slip direction occurring close to the direction of maximum shear stress than is the case under uniaxial loading?

Mr. Peterson has given a very complete treatment of this point in a recent paper.[3]

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[1] Chief, Mechanical Metallurgy, U. S. Department of Commerce, National Bureau of Standards, Washington, D. C.

[2] H. J. Gough, "Some Experiments on the Resistance of Metals to Fatigue Under Combined Stresses," Res. Coun., R & M 2522 H. M. Stationery Office (1951).

[3] Mr. Peterson has given a very complete treatment of this point in a paper presented by the Colloquium on Fatigue in Stockholm To be published by Springer Verlog.

MR. E. H. SCHUETTE.[4] — In line with the remarks by Mr. Bennett, we have seen considerable evidence of directional differences in fatigue strength of magnesium-alloy extrusions, that would appear to stem from causes other than anisotropy of the metal itself. Extruded products often show higher fatigue strengths longitudinally than they do transversely. When the bars are notched, however, we find identical longitudinal and transverse results. This leads us to believe that the base transverse curve is in reality a curve for slightly notched bars, the notch stemming from internal structure. Because of the elongation of various constituents that occurs in the extrusion process, these notches are so attenuated as to be ineffective in the longitudinal direction.

MR. P. N. MATHUR (*author*). — The crystallographic texture or the actual difference in the properties of the metal itself, as suggested by Mr. Bennett may also have an influence on the anisotropy in fatigue, but the mechanical texture (such as elongated inclusions) appears to be the most significant cause of anisotropy in the fatigue properties of formed metals. The results of fatigue tests for anisotropy in bending and torsion by Ransom (**6**)[5] indicate that in all cases except for longitudinal bending the cracks originated at the inclusions. These results are explainable qualitatively from the consideration of inclusions as causing a micro stress-concentration or microstrain concentration as discussed in the paper.

In connection with Mr. Schuette's remarks, I would like to point out another instance (**8, 16**) where similar behavior of a notch on anisotropy in bending fatigue was observed for nickel-chromium steel. It appears that in the presence of an external notch the effect of an internal notch becomes secondary.

MR. R. E. PETERSON.[6] — Where the specimens were cut at 45 deg to the rolling direction, one would expect 45 deg stringers at two opposite locations on the cylinder and nearly round intersections of the stringers at right angles to the above positions. Since the stress distributions are different in these locations it would be interesting to know where the cracks started. It must be recognized that with "stress concentrators" and with slip and normal stress contributing to failure (as emphasized by the authors), the analysis becomes quite complicated. Perhaps something could be done utilizing Neuber's solutions for elliptical holes. This, incidentally, leads to another question; have the authors made, or do they know of, comparative bending and torsion fatigue tests of clean material (such as vacuum melted)?

MR. MATHUR. — Mr. Peterson has raised an interesting point indicating the difference between the type of stress concentration that occurs at the intersection of the longitudinal or diagonal inclusion on the cylinder and that at the elongated portion of the inclusion. We made some observations on the type of cracks that appeared on torsion specimens. The trend seemed to indicate that the cracks ran parallel to the direction of inclusions; that is, the cracks ran longitudinally on longitudinal specimens and transversely on transverse specimens.

The comparative bending and torsion data on relatively clean metal (inclusion-free), as pointed out by Mr. Peterson, will be very helpful in the study of the effect of state of stress on the anisotropy in fatigue. The authors do not know of any test on a clean steel that have been made both in bending and torsion.

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[4] Metallurgical Laboratories, The Dow Chemical Co., Midland, Mich.

[5] The boldface numbers in parentheses refer to the list of references appended to the paper, see p. 937.

[6] Manager, Mechanics Department, Westinghouse Research Labs., East Pittsburgh, Pa.

MR. W. N. FINDLEY (*author's closure*).—The authors are grateful to the discussors for their stimulating comments. The views of Messrs. Bennett and Schuette agree with those previously held by the author as expressed in earlier papers (**30, 1**)[5] in which a method of correcting for anisotropy based on stress concentration at elongated inclusions was proposed. The authors have been remiss perhaps in not bringing out more clearly the relation of this concept to the present discussion, but it was thought unnecessary to limit the discussion at this point to specific mechanisms for the influence of texture. As pointed out in the text, the concepts of the shear stress theory and texture (stress concentration from inclusions for example) fail to satisfy three out of the four possible correlations cited. When the possible influence of the normal stress on shear planes was introduced most of the possible correlations were satisfied.

The ratio of torson to bending fatigue strengths cited by Mr. Bennett must be based on shear stress for both strengths. This being true, these ratios for the materials described in the paper were also in the same range of about 1.2 to 1.3.

Mr. Bennett's suggestion that there are many more planes having the same value of maximum shear stress in uniaxial stress than in torsion (biaxial tests) is plausible and may be a contributing factor in this complex problem. It seems unlikely that this is the only or perhaps major factor, however. This factor would not explain, for example, the difference in fatigue strength under uniaxial loading with the superimposed static tensile stress compared to the fatigue strength with superimposed compression stress[7] since the same number of shear planes are available in both instances.

Also, with the addition of even a slight amount of torsion to bending, the state of stress is changed from uni-axial to biaxial with a resulting reduction in the number of planes having the same shear stress from infinite to two. With the introduction of torsion there is, however, no sharp rise in strength (based on principal shear stress), but a gradual increase as the percentage of torsion is increased as shown in Fig. 19 of my 1953 paper (**1**) and Fig. 7 of the 1954 paper (**2**). Some transition region might, of course, be expected. However, in the data cited, such a transition (if a transition is involved) was not complete until the shear stress from torsion was 1.732 or more times the shear stress contributed from bending.

In a biaxial state of stress in which the stresses are equal tensions, the number of possible shear planes is only four, so that the fatigue strength based on shear stress should be greater than for uni-axial tension according to Mr. Bennett's suggestion. Of the eight sets of fatigue data on biaxial tension at hand, two do not include tests exactly at equal tensions, one having some anisotropy shows a higher fatigue strength under equal biaxial tension than uniaxial tension, two having negligible anisotropy show a lower fatigue strength in biaxial tension, and three show lower fatigue strengths in biaxial tension, but have substantial anisotropy. Thus the interpretation is uncertain.

In answer to Mr. Peterson's question, the test specimens have all been preserved with a view to making a detailed study of the origin of the fractures. However, to date it has not been possible to complete this work.

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EFFECT OF ALLOY CONTENT ON THE METALLOGRAPHIC CHANGES ACCOMPANYING FATIGUE*

By M. S. Hunter[1] and W. G. Fricke, Jr.[1]

Synopsis

The microstructural changes accompanying fatigue action have been followed for a series of binary aluminum-magnesium alloys. It is shown that alloy additions are responsible for marked differences in the microscopically observed deformation and progressive failure, there being a gradual transition with increasing solute concentration from the behavior typical of pure aluminum to that typical of the structural aluminum alloys. Fatigue, with increasing alloy additions, becomes an increasingly local phenomenon, suggesting that the reason not all alloy additions are accompanied by the expected increase in fatigue strength lies in the existence of localized areas weak in fatigue. Displacement of the curves of progressive change by the alloy addition are shown, as well as displacement of the *S-N* curve denoting failure.

It is shown that the amount of fatigue deformation observed on the surface of a specimen is a two-part exponential function of the number of test cycles. Quantitative results show how the amount of deformation is related to the stress, cycles, and alloy content.

The general lack of correlation between the fatigue strength of alloys and their static strength has aroused speculation regarding the manner in which alloying additions affect fatigue behavior and the reason that additions which produce a pronounced increase in static strength do not always develop a proportionate increase in fatigue strength (**1**).[2] This paper describes the manner in which the microscopic changes resulting from fatigue action are altered by additions of magnesium to high-purity aluminum and explains the differences in observed behavior between pure aluminum and aluminum alloys. Also, a quantitative relationship between the amount of surface deformation and the number of stress cycles is given and is applied to these high-purity base aluminum-magnesium alloys.

The metallographic changes that occur on the surface of a specimen during a fatigue test have been observed previously (**2, 7**), and it has been shown that slip is an intimate part of the fatigue mechanism. Early in a test, slip occurs in the specimen, the amount of slip increasing exponentially with the number of cycles until a "slip saturation" point is reached, after which new slip bands form at a reduced rate. At some time after the slip saturation point, small cracks begin to form along pre-existing slip bands. Initially, these small cracks are confined to individual grains, but eventually, with continued stressing, some cracks cross grain boundaries to form major cracks, joining up with cracks in adjacent grains wherever possible. These cracks grow both in extension and depth until the effective cross-sectional area is too small to withstand the imposed load and the specimen fails with a tensile type fracture.

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* Presented at the Fifty-eighth Annual Meeting of the Society, June 26–July 1, 1955.

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[2] The boldface numbers in parentheses refer to the list of references appended to this paper, see p. 953.

TABLE I.—PROPERTIES OF MATERIALS.

	1 per cent Magnesium Alloy	2 per cent Magnesium Alloy	3 per cent Magnesium Alloy	4 per cent Magnesium Alloy	Pure Aluminum[a]
Composition, weight per cent:					
Magnesium	0.97	2.00	2.82	4.04	0.001
Copper	0.01	0.01	0.01	0.01	0.006
Iron	0.004	0.005	0.004	0.022	0.18
Silicon	0.00	0.00	0.00	0.00	0.06
Mean Grain Diameter, mm	0.18	0.12	0.11	0.071	0.081
Tensile Strength, psi:					
Longitudinal	15 000	21 400	25 900	32 000	9 400
Transverse	15 100	21 200	24 100	30 400	...
Yield Strength (0.2 per cent offset), psi:					
Longitudinal	4 300	6 800	8 700	11 800	4 800
Transverse	4 800	6 800	7 900	11 300	...
Elongation in 2 in., per cent:					
Longitudinal	29.2	26.5	25.5	27.5	44.8
Transverse	24.8	28.0	25.5	28.2	...

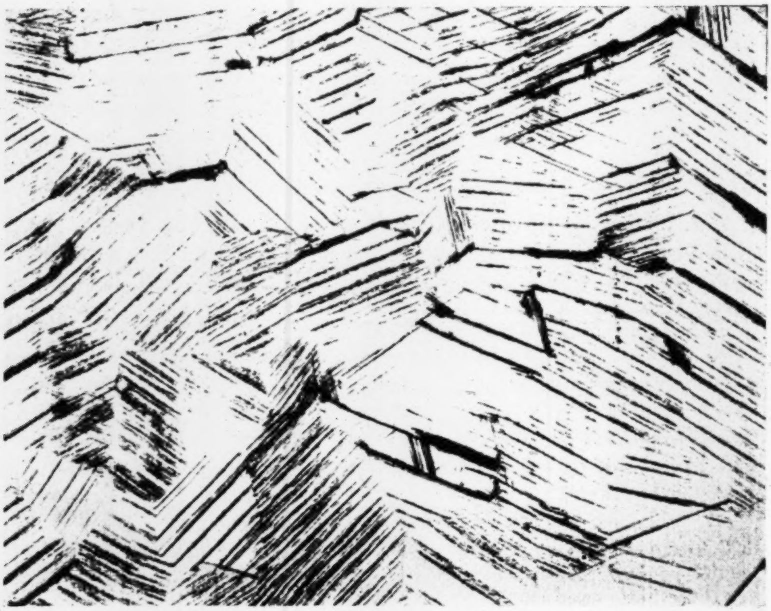
[a] DD1S-0 (1230-0) reported in reference (**2**).

If the number of cycles required to produce the various stages of progressive change are noted for several stress levels, the points when plotted will lie on smooth curves related to the conventional S-N curve denoting failure (**2**). These "curves of progressive change" for commercial purity aluminum are roughly parallel to the failure curve. In the structural aluminum alloys, such as 2024-T3 and 7075-T6, these curves approach the failure curve at low stresses.

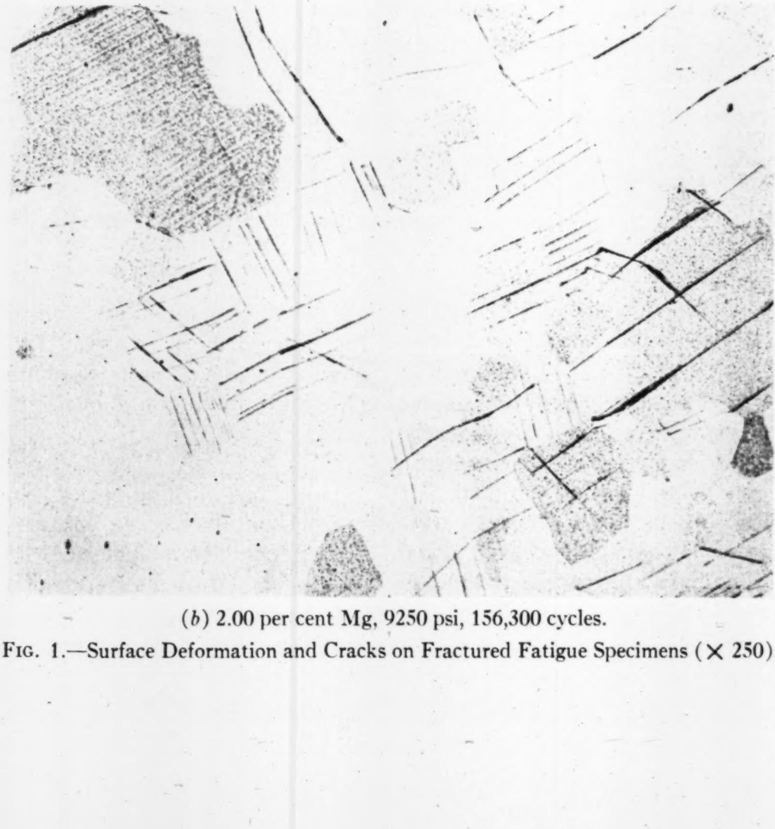
Previous investigations have disclosed that the resistance of aluminum to cyclic loading as well as its static strength may be increased by the presence of magnesium in solid solution (**3, 4**). No attempt was made by these investigators, however, to ascertain how this improvement was effected. The present investigation was undertaken to establish by metallographic techniques the manner in which alloy additions such as magnesium affect the behavior of aluminum and to explain the differences in observed fatigue behavior between pure aluminum and structural aluminum alloys.

MATERIAL

Four lots of high-purity aluminum-magnesium alloy sheet, containing from 1 to 4 per cent magnesium, were prepared for this investigation. Unalloyed aluminum was used for comparison. Machined specimens of each alloy were heat treated for 16 hr at 700 F to place the magnesium in solid solution and were

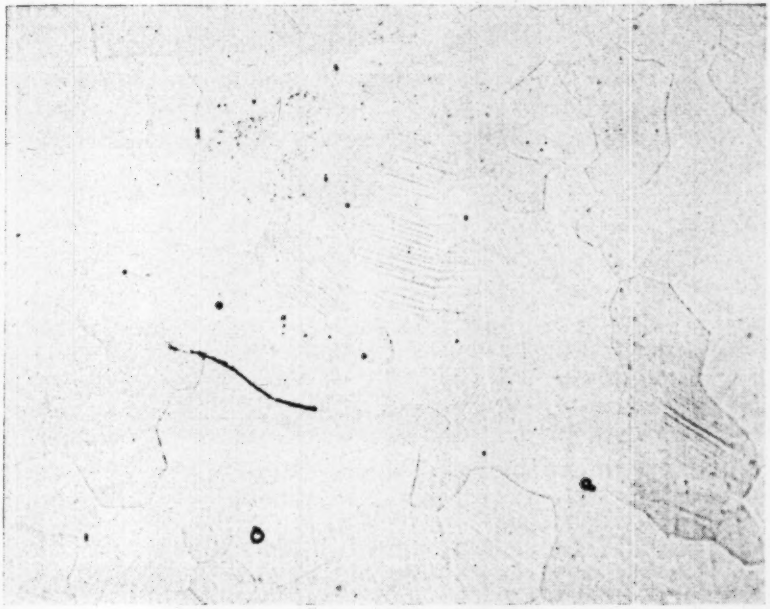


(*a*) 0.97 per cent Mg, 6250 psi, 148,700 cycles

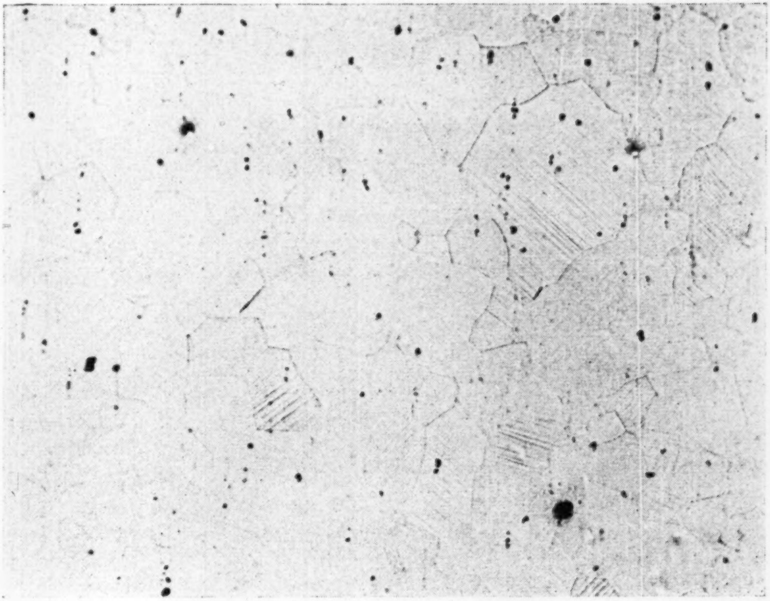


(*b*) 2.00 per cent Mg, 9250 psi, 156,300 cycles.

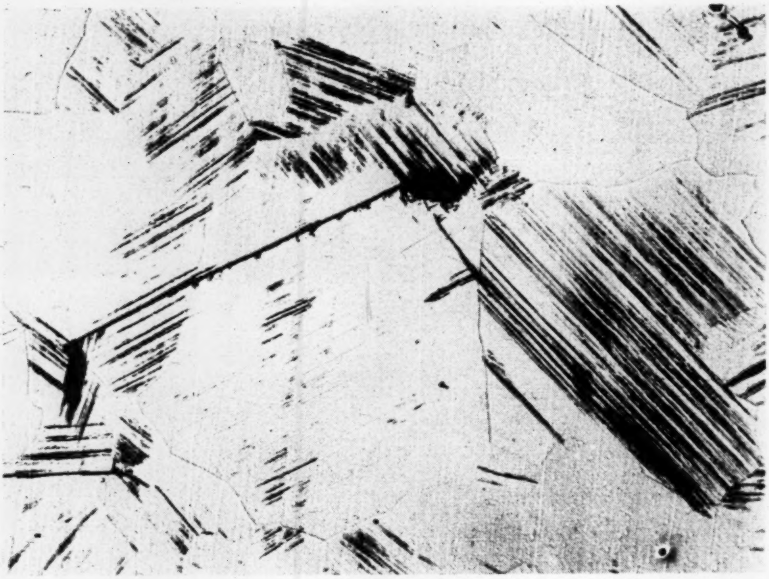
FIG. 1.—Surface Deformation and Cracks on Fractured Fatigue Specimens (× 250).



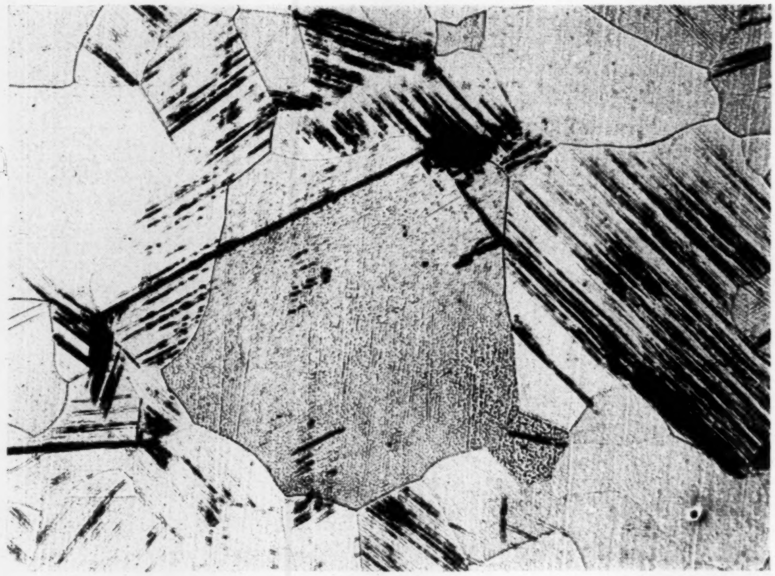
(*c*) 2.82 per cent Mg, 12,700 psi, 155,900 cycles.



(*d*) 4.04 per cent Mg, 17,500 psi, 99,500 cycles.
FIG. 1.—(*Continued.*)



(*a*) Before caustic etching.



(*b*) After caustic etching.

FIG. 2.—Crack Detection by Caustic Etch in 0.97 per cent Mg Alloy (× 250).

individually quenched in cold water to retain the magnesium in solid solution. The chemical and mechanical properties of the four alloys and the unalloyed aluminum, DD1S-0 (1230-0), are given in Table I.

EXPERIMENTAL PROCEDURE

Cantilever sheet specimens were machined with their axes parallel to the rolling direction. After heat treatment, all specimens were chemically polished to produce a metallographic finish and to develop the microstructure. Testing was done in alternate flexure at constant deflection, the imposed stress being calculated from the deflection produced in a calibration specimen by known loads (5). As elastic formulas were used in computing the stresses and much of the testing was conducted at stresses above the yield strengths of the materials, the values of stress above the yield strength must be considered as nominal only. The tests were interrupted periodically, and plastic replicas were made of the specimen surface. These replicas, which provided a permanent record of the microscopic changes in surface appearance resulting from fatigue action, were examined microscopically at several magnifications with the light microscope.

TEST RESULTS

General Metallographic:

In general, the binary aluminum-magnesium alloys went through the same fatigue-induced stages of slipping and cracking as were observed with unalloyed aluminum. The alloying additions, however, had a pronounced effect on the details of the deformation and cracking which led to ultimate failure.

Changes in the total amount of surface deformation resulting from alloying additions were very pronounced and could even be observed visually. Because of the highly specular nature of the specimen surface, the presence of slip could be detected even by the naked eye as a "frosting" of the surface. With unalloyed aluminum, frosting was very pronounced, but with increasing amounts of magnesium frosting decreased until, with the highest magnesium concentration, little loss in the specularity of the surface was apparent. This change in degree of deformation was even more evident under microscopic examination. With increasing magnesium contents, both the number of grains affected by slip and the amount of slip within the grains decreased.

In addition to reducing the amount of surface deformation resulting from slip, the alloying additions also progressively changed the character of the deformation. With increasing magnesium content, the slip deformation changed from widespread, multiple slip characteristic of unalloyed aluminum to more simple slip systems consisting generally of single, straight bands across individual grains. These bands in the high-magnesium alloys sometimes were relatively wide, giving a furrowed appearance to the grain. Figure 1 illustrates these progressive differences in surface deformation on specimens of the four alloys which failed in comparable times.

The metallographic changes resulting from alloying were not restricted to stages involving slip but were also evident in the stages involving cracking. In the 1 per cent magnesium alloy, a majority of all slip bands had been the site of the formation of cracks by the time the specimen had failed. Whereas most of these cracks were extremely shallow, an appreciable number did deepen. Figure 2 illustrates the slip and cracks in one of these specimens after etching by a caustic treatment which widens metal discontinuities such as cracks but leaves uncracked slip steps little affected. It will be noted in Fig. 2

that a majority of the lines evident in this area were actually cracks but that some of the individual lines consist of both slip and cracks. This illustrates very conclusively the intimate relation between slipping and cracking.

With increasing alloy content, the amount of visible cracking decreases, but as the number of cracks decreases the severity of the individual cracks appears to increase. As the magnesium content is raised, fewer cracks are formed, especially at low stresses where only one crack may be seen before the specimen fails. In such an instance, the real existence of a crack-joining stage is problematical. At higher alloying concentrations, it becomes increasingly difficult to resolve the slip band upon which a crack later forms so that it sometimes appears that cracks form in unslipped regions. This is the behavior typical of the structural alloys where slip is seldom seen. It seems likely, however, that even in these cases cracks are formed as the result of a slip mechanism, the slip itself being invisible because the method of observation is not sufficiently sensitive.

In addition to these stages of progressive change, some movement of entire grains relative to each other along their mutual boundaries was noted. This feature was observed in unalloyed aluminum and in the 1 per cent magnesium alloy but was very difficult or impossible to establish in the stronger alloys. In these latter alloys, however, there was occasionally evidence of intergranular cracking which may in reality have been slip to failure.

In this investigation, examinations were made for fatigue-induced precipitation similar to that reported in the literature (**6**). None was found, indicating

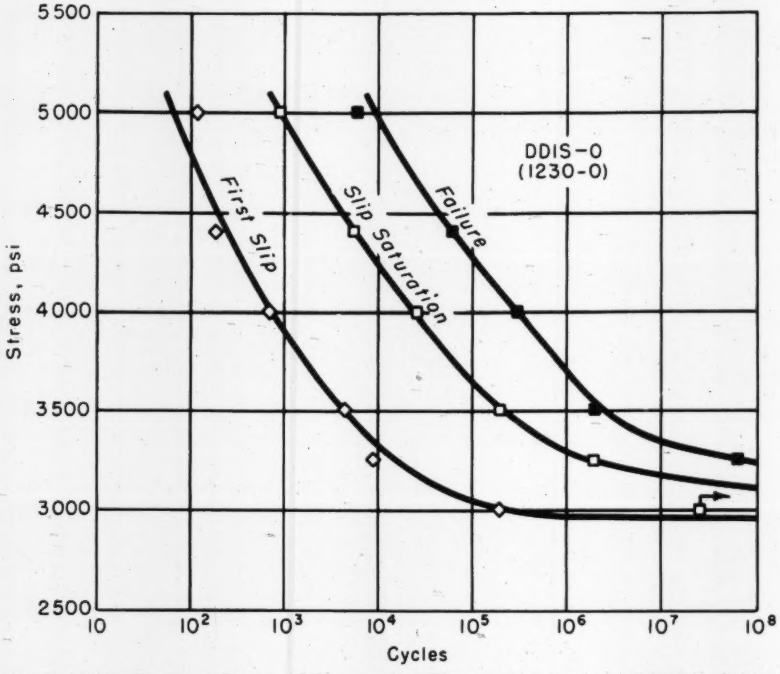


FIG. 3.—Relation Between Stages of Progressive Change Observed on DD1S-0 (1230-0) Sheet (Reference (**2**)).

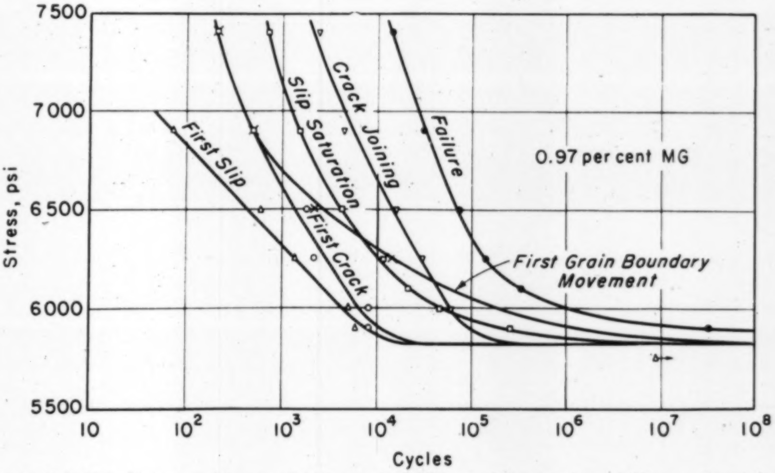


FIG. 4.—Relation Between Stages of Progressive Change Observed on 0.97 per cent Magnesium Alloy.

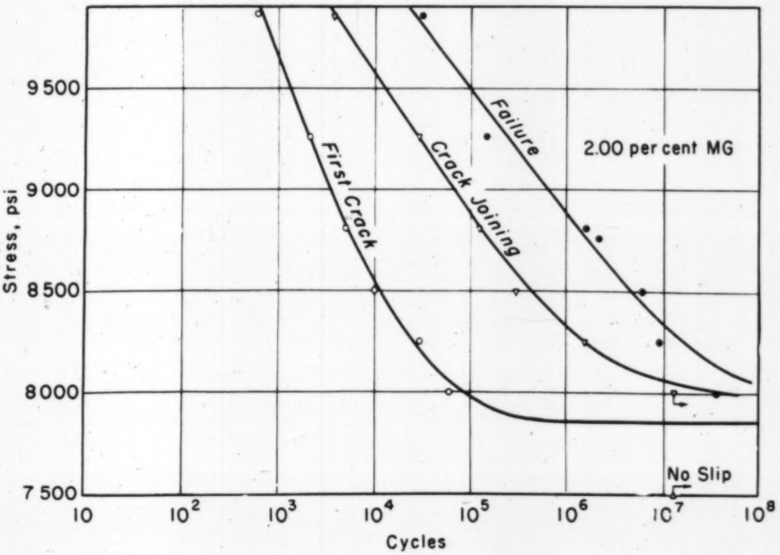


FIG. 5.—Relation Between Stages of Progressive Change Observed on 2.00 per cent Magnesium Alloy.

that any precipitate which might have formed was of submicroscopic size.

Curves of Progressive Change:

As expected, the increase in alloy content raised the *S-N* curves denoting failure to higher stress levels. There was also the expected shifting of the curves of progressive change which plot the entrance of a specimen into a new stage of deformation (Figs. 3 to 7). It is interesting to note the relative locations of the same curve for the various alloys,

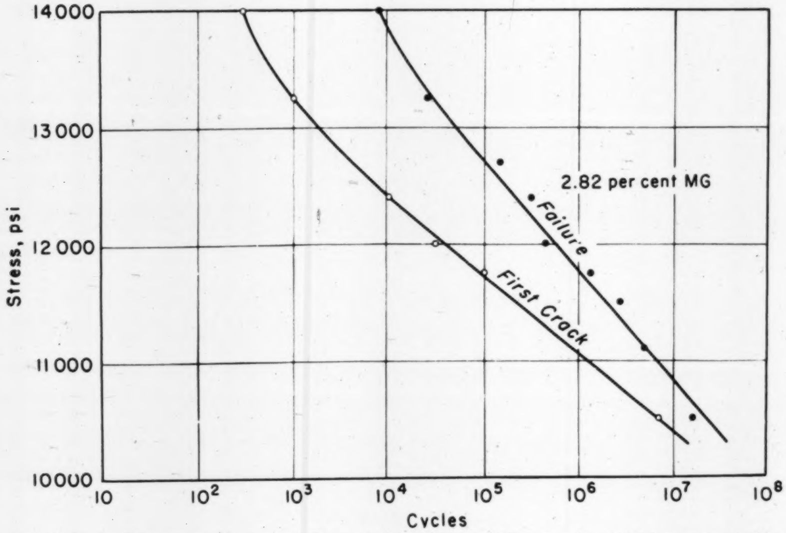


FIG. 6.—Relation Between Stages of Progressive Change Observed on 2.82 per cent Magnesium Alloy.

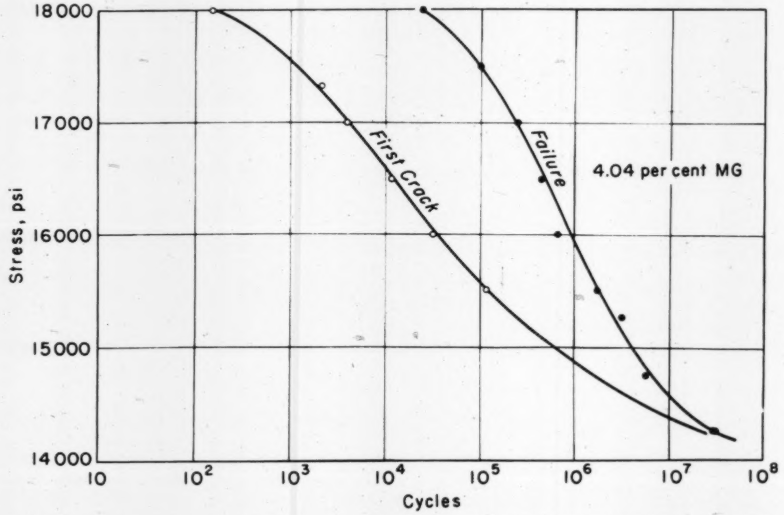


FIG. 7.—Relation Between Stages of Progressive Change Observed on 4.04 per cent Magnesium Alloy.

especially at stress levels which result in equal lives for each material.

The most surprising change was noted with the "first slip" curve which is shifted radically to the left, with the result that in specimens of comparable life, slip is seen earlier in those with the higher magnesium content. Whereas several hundreds or thousands of cycles had passed before the first slip band was seen in unalloyed aluminum or the 1 per cent alloy, slip was always seen in the first few cycles in the stronger alloys, occasionally even in the first cycle. Consequently, first slip curves could not be plotted for the alloys containing over 1 per cent magnesium. Another interesting observation was the presence of slip in these higher strength alloys at stresses appreciably below the conventional endurance limit. This indicates either that the "endurance limit at infinite cycles" is appreciably below the conventional endurance limit or that slip induced in the initial stages can strengthen a material sufficiently to prevent subsequent failure.

The curve showing the occurrence of the first crack is not affected appreciably by the alloying additions at high stress levels, but is shifted toward a greater number of cycles at low stress levels. This shifts the curve from near parallelism with the failure curve in the 1 and 2 per cent magnesium alloys to increasing convergence as the magnesium content is increased further. This convergence of the cracking and failure curves at low stress levels is typical of structural aluminum alloys.

Movement of grains along their mutual boundaries was noted only in unalloyed aluminum and in the 1 per cent magnesium alloy. At high and medium stresses, the movement was first noticed about the same time the first crack appeared, but at low stresses it occurred somewhat later (Fig. 4).

The curve of slip saturation, which marks a change in the rate of adding new deformation features (both slip bands and cracks) to the microstructure, also undergoes a change with additions of magnesium. In the alloys with high magnesium content, this change in rate is not abrupt and the amount of deformation is so small as to preclude experimental determination of the slip saturation point. In the 1 per cent magnesium alloy, for which this point could be established, the slip saturation curve is shifted toward a greater number of cycles. It is interesting to note that, as a result of this shift, the slip saturation point no longer coincides with the point of first cracking but occurs somewhat later in the fatigue life. Indirect evidence had led to the conclusion that in unalloyed aluminum cracking was the result of a saturation of the material by slip (2), but it now appears that, in alloys, *local* areas become saturated before the material as a whole and, consequently, that localized conditions may control fatigue behavior.

Amount of Deformation Curves:

The amount of surface-evident deformation was determined quantitatively by the grid-intercept method described previously (2). A series of deformation-cycle curves was determined in detail for the 1 per cent magnesium alloy and compared with typical curves for other alloys. In this manner, the variation in amount of deformation could be related to the parameters of stress, cycles, and alloy content.

When plotted on a double logarithmic scale, the deformation curve for any test consists of two straight lines which intersect at the slip saturation point. The equation of either portion of the curve, therefore, is of the form:

$$\frac{L}{A} = cN^m \quad \ldots\ldots\ldots\ldots\ldots (1)$$

where:

m = the slope of the straight line,

c = the value of L/A at $N = 1$,

L/A = the total length of deformation lines per unit area, and

N = the number of cycles.

The constants c and m (given a subscript 1 for the first branch of the curve and subscript 2 for the portion after the slip saturation point) vary with test conditions and illustrate the effect of stress level and alloying.

The deformation curves for the 1 per cent alloy are given in Fig. 8, and the deformation constants derived from these curves are indicated in Table II. For this alloy, as the test stress increased, the constants m_1 and m_2 increased (the curves became steeper), c_1 decreased, and c_2 remained almost constant. Thus, deformation increases with increasing stress and increasing number of stress cycles. No simple relation could be found between the stress level and the constants, although there did exist a direct proportionality between the amount of deformation existing at the slip saturation point and the test stress. The amount of deformation present at failure appears to be a two-part exponential function of cycles since the failure points in Fig. 8 lie on a pair of intersecting straight lines.

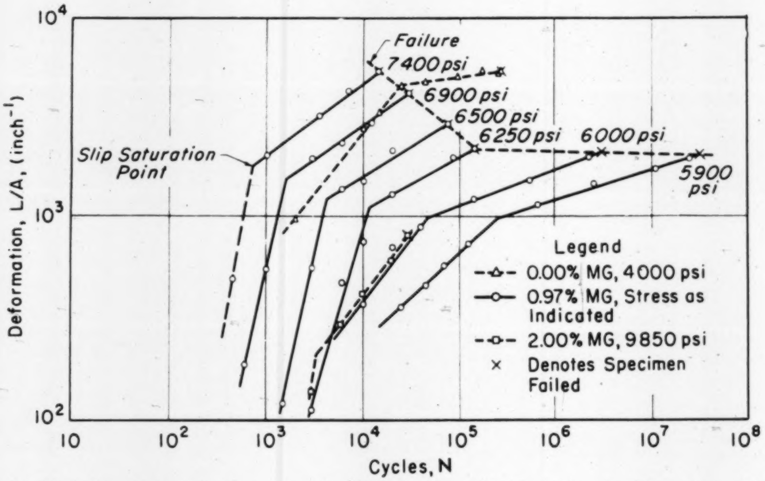


FIG. 8.—Relation Between Amount of Surface-Evident Deformation and Number of Cycles.

Included in Fig. 8 are typical curves for two other materials—unalloyed aluminum and a 2 per cent magnesium alloy. These curves confirm the visual observation that alloying decreases the amount of deformation and illustrate the effect of solute content on the deformation constants. The values of both m_1 and m_2 increase appreciably with alloying. Also, these two constants approach each other in magnitude which explains the difficulty in detecting a slip saturation point in the stronger alloys.

TABLE II.—DEFORMATION CONSTANTS OF 0.97 PER CENT MAGNESIUM ALLOY.

Stress, psi	m_1	m_2	$\log_{10} c_1$	$\log_{10} c_2$
5900	0.44	0.14	0.63	2.24
6000	0.63	0.21	0.06	2.00
6250	1.69	0.27	−3.83	2.04
6500	2.22	0.30	−4.99	2.00
6900	2.40	0.34	−4.43	2.16
7400	2.88[a]	0.37	−4.94[a]	2.20

[a] Estimated value.

CONCLUSION

This investigation has shown that the additions of alloying elements to aluminum, as typified by additions of magnesium, bring about pronounced changes in the surface deformation and crack configuration resulting from cyclic loading. With unalloyed aluminum, most areas of a specimen behave similarly, and extensive deformation and cracking take place before failure. With alloys, a smaller proportion of the grains is visibly affected by fatigue, the amount of slip deformation is decreased, although initial slip is observed after a smaller number of cycles, a smaller percentage of the slip bands which form reaches the cracking stage, and fewer of the cracks which form leave the confines of the parent grain. With alloys, the changes in surface features are highly localized with the result that certain areas may show extensive change while adjoining areas appear to be unaffected. Thus, it appears that, whereas alloying additions increase static strength, they make fatigue an increasingly localized phenomenon and, therefore, that it is localized weakness rather than over-all strength which controls fatigue behavior.

Acknowledgment:

The authors express their appreciation to F. Keller, under whose direction this investigation was conducted, and to members of the Mechanical Testing Division of the Aluminum Research Laboratories who conducted the fatigue tests.

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DISCUSSION

MR. R. E. PETERSON.[1] — Forsyth at Farnborough, England, has observed a slip extrusion phenomenon in fatigue tests of age hardenable aluminum alloys as shown in the accompanying Fig. 9. Have the authors observed this in any of their investigations?

MESSRS. M. S. HUNTER AND W. G. FRICKE, JR. (*authors' closure*). — The slip band extrusion effect, if it does exist, is an interesting phenomenon resulting from the accelerated aging characteristics of alloys subjected to cyclic stressing. While experiments specifically designed to ascertain its occurrence were not conducted, alloys have been tested which, according to Forsyth's work, should have shown the effect. Unfortunately, the replica technique used in a large portion of the work is not particularly adaptable to this particular observation. Therefore, although slip band extrusion was not observed, it cannot be said that this phenomenon never occurs.

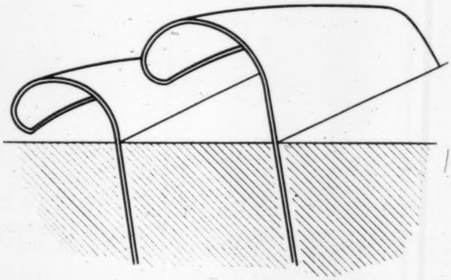

FIG. 9.

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[1] Mechanics Department, Westinghouse Research Labs., East Pittsburgh, Pa.

AXIAL-STRESS FATIGUE STRENGTHS OF SEVERAL STRUCTURAL ALUMINUM ALLOYS*

BY F. M. HOWELL[1] AND J. L. MILLER[2]

SYNOPSIS

The efficient use of materials for applications involving repeated axial loading in tension or compression requires some knowledge of their behavior under such conditions. The fact that there are many combinations of maximum and minimum stress and number of cycles to be withstood, and the additional fact that no two lots of material behave exactly the same, necessitates making a fairly large number of tests of different lots of material.

This paper presents the results of tests of a number of lots of 2014-T6 (CS41A-T6), 2024-T4 (CG42A-T4), 6061-T6 (GS11A-T6), and 7075-T6 (ZG62A-T6) aluminum alloys and shows, through the construction of modified Goodman diagrams, how the results of tests at six ratios of minimum to maximum stress are used to reinforce each other. These diagrams provide a basis for final tabulations of average or typical fatigue strengths.

Most of the fatigue data available on aluminum alloys, and for that matter on any group of materials, have been obtained from simple rotating-beam fatigue tests. The reason for this is that rotating-beam testing machines are relatively inexpensive, the tests can be made quite easily, and they can be run at rather high speeds. This makes it possible to obtain a large amount of data at low cost and in a relatively short period of time. Such tests are necessarily limited, however, to conditions where the ratio of minimum stress to maximum stress is −1.0. The results, nevertheless, are useful for comparing one alloy with another.

In service, there are many applications where fluctuating tensile and compressive stresses occur that are neither completely reversed nor bending stresses. To obtain data applicable to these conditions, axial-stress fatigue tests are made in which stress ratios other than −1.0 and mean stresses other than zero can be applied. In such tests the load is uniformly distributed throughout the cross-section of a test specimen. The accumulation of such data is time-consuming, but the greater amount of resulting fatigue information more than compensates for this.

It is well known that for any alloy the actual tensile properties may differ somewhat from lot to lot. These differences depend upon many factors, including actual composition, product, size, and internal structure. The fatigue properties also may differ depending upon various factors; therefore, tests of a single sample cannot adequately define the fatigue strength of an alloy. In order to establish fatigue strengths representative of an alloy, it is necessary to test a variety of the products, shapes, and sizes in which it is offered commercially.

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* Presented at the Fifty-eight Annual Meeting of the Society, June 26-July 1, 1955.

[1] Chief, Mechanical Testing Division, Aluminum Research Laboratories, New Kensington, Pa.

[2] Research Engineer, Mechanical Testing Division, Aluminum Research Laboratories, New Kensington, Pa.

TABLE I.—TENSILE PROPERTIES OF MATERIALS TESTED.

Sample	Product	Size, in.	Tensile Strength, psi	Yield Strength,[a] psi	Elongation in 2 in., per cent
		2014-T6 (CS41A-T6)			
No. 1	Drawn rod	¾ diam	69 000	61 000	12.0
No. 2	Rolled bar	1 × 7½	71 400	63 200	11.5
No. 3	Rolled bar	1 × 7½	67 300	60 500	11.0
No. 4	Forged slab	⅞ thick	70 600	62 400	11.3
No. 5	Extruded rod	1¼ diam	78 200	71 800	9.0
No. 6	Extruded bar	1¼ × 4	75 400	68 300	10.0
	Typical values[b]		70 000	60 000	13.0
		2024-T4 (CG42A-T4)			
No. 1	Drawn rod	¾ diam	70 500	42 000	21.3
No. 2	Drawn rod	¾ diam	71 300	45 300	20.0
No. 3	Rolled bar	1 × 7½	64 800	42 000	20.0
No. 4	Extruded rod	1¼ diam	83 300	65 200	10.0
No. 5	Extruded bar	1¼ × 4	85 300	65 700	10.5
No. 6	Extruded bar	1¼ × 4	82 600	64 900	14.0
	Typical values[b]		68 000	48 000	19.0
		6061-T6 (GS11A-T6)			
No. 1	Drawn rod	¾ diam	46 000	39 200	21.0
No. 2	Rolled bar	1 × 7½	43 000	37 400	19.2
No. 3	Rolled bar	1 × 7½	43 800	41 800	15.0
	Typical values[b]		45 000	40 000	17.0
		7075-T6 (ZG62A-T6)			
No. 1	Drawn rod	¾ diam	81 300	70 300	15.0
No. 2	Drawn rod	¾ diam	83 800	72 600	14.0
No. 3	Drawn rod	¾ diam	87 500	76 400	15.5
No. 4	Rolled rod	1¼ diam	82 200	70 500	15.0
No. 5	Rolled bar	1 × 7½	87 000	78 700	10.5
No. 6	Extruded rod	1¼ diam	92 200	84 600	9.0
No. 7	Extruded bar	1¼ × 4	94 900	87 800	9.0
No. 8	Extruded bar	1¼ × 4	88 300	80 400	11.5
	Typical values[b]		82 000	72 000	11.0

[a] Offset = 0.2 per cent.

[b] Typical values are from Alcoa Aluminum and Its Alloys, 1950.

It is the object of this paper to present the typical values that have been established by the Aluminum Research Laboratories for the fatigue strength of the more important structural wrought aluminum alloys, 2014-T6 (CS41A-T6), 2024-T4 (CG42A-T4), 6061-T6 (GS11A-T6), and 7075-T6 (ZG62A-T6).

MATERIAL

Over the past several years, a number of products of these alloys, including drawn rod, rolled bar, forged slab, and extruded rod and bar, have been tested. The materials, all produced commercially, have tensile properties exceeding minimum specification requirements. For each alloy, the kind of product, its size, and its tensile properties are shown in Table I.

TABLE II.—TYPICAL AXIAL-STRESS FATIGUE STRENGTHS AT VARIOUS STRESS RATIOS FOR 2014-T6, 2024-T4, 6061-T6, AND 7075-T6 ALLOYS.

Alloy and Temper	Stress Ratio, *R*[a]	Approximate Maximum Stress[b] for Number of Cycles Indicated, psi					
		10 000 Cycles	100 000 Cycles	1 000 000 Cycles	10 000 000 Cycles	100 000 000 Cycles	500 000 000 Cycles
2014-T6.	+0.5	+70 000	+68 000	+59 000	+56 000	+54 000	+53 000
	0.0	+66 000	+54 000	+42 000	+36 000	+32 000	+30 000
	−0.5	+56 000	+42 000	+32 000	+26 000	+22 000	+20 000
	−1.0	+45 000	+33 000	+25 000	+20 000	+17 000	+15 000
	−2.0	. . .	+22 000	+17 000	+13 000	+11 000	+10 000
	−∞	. . .	. . .	−49 000[c]	−40 000[c]	−33 000[c]	−30 000[c]
2024-T4.	+0.5	. . .	+66 000	+57 000	+53 000	+52 000	+51 000
	0.0	. . .	+54 000	+44 000	+37 000	+34 000	+33 000
	−0.5	. . .	+43 000	+34 000	+27 000	+24 000	+23 000
	−1.0	. . .	+35 000	+27 000	+21 000	+18 000	+17 000
	−2.0	. . .	+24 000	+18 000	+14 000	+12 000	+11 000
	−∞	. . .	. . .	−51 000[c]	−41 000[c]	−36 000[c]	−34 000[c]
6061-T6.	+0.5	+45 000	+44 000	+41 000	+38 000	+37 000	+36 000
	0.0	+44 000	+38 000	+31 000	+26 000	+23 000	+22 000
	−0.5	+39 000	+31 000	+24 000	+19 000	+16 000	+15 000
	−1.0	+33 000	+25 000	+19 000	+15 000	+13 000	+12 000
	−2.0	+24 000	+18 000	+13 000	+11 000	+9 000	+8 000
	−∞	. . .	. . .	−40 000[c]	−33 000[c]	−29 000[c]	−27 000[c]
7075-T6.	+0.5	+82 000	+75 000	+63 000	+58 000	+56 000	+55 000
	0.0	+75 000	+57 000	+45 000	+38 000	+36 000	+35 000
	−0.5	+64 000	+46 000	+35 000	+29 000	+27 000	+25 000
	−1.0	+53 000	+38 000	+28 000	+23 000	+21 000	+20 000
	−2.0	. . .	+28 000	+20 000	+16 000	+15 000	+14 000
	−∞	. . .	. . .	. . .	−54 000[c]	−50 000[c]	−46 000[c]

[a] $R = \frac{\text{Minimum Stress}}{\text{Maximum Stress}}$.

[b] Plus (+) means tension; minus (−) means compression.

[c] Minimum stress (maximum stress = 0).

Method of Test:

The axial-stress fatigue data considered were obtained from tests in machines designed and constructed by the Aluminum Research Laboratories as described some years ago by R. L. Templin.[3] One end of a test specimen is attached to a crosshead actuated by a rotating variable eccentric bearing. The opposite end of the specimen is attached to a link dynamometer whose load-deflection characteristics are known to very close limits. The machines can apply loads up to ±1800 lb at 2000 cpm.

The design of the machine is such that

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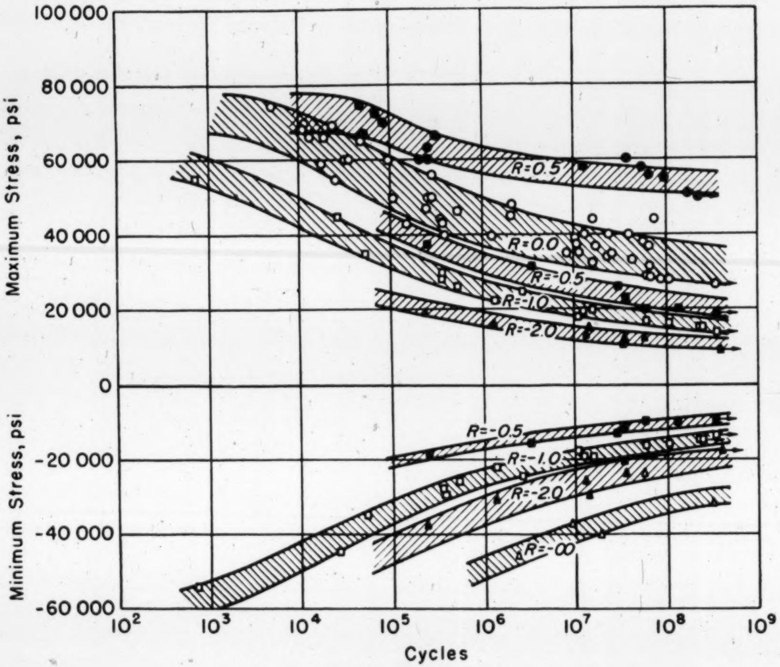
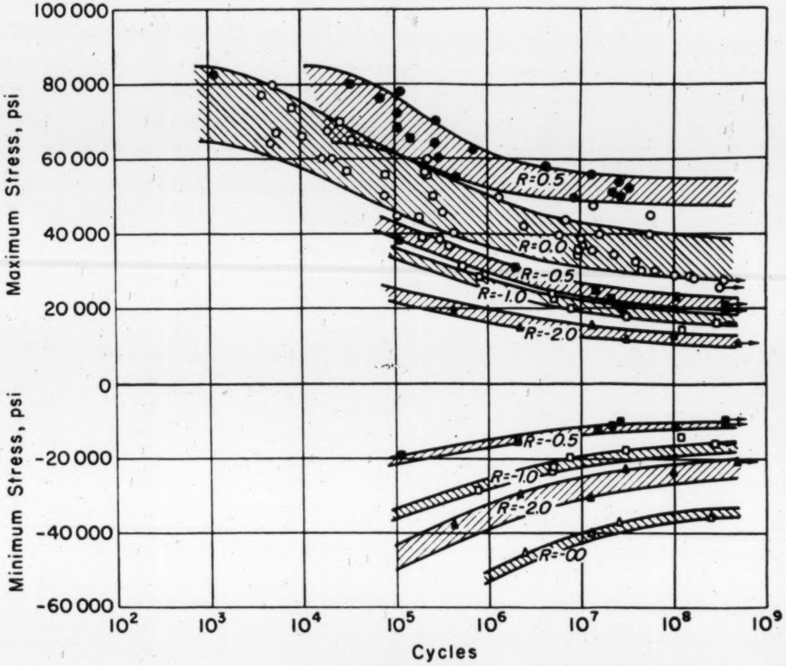
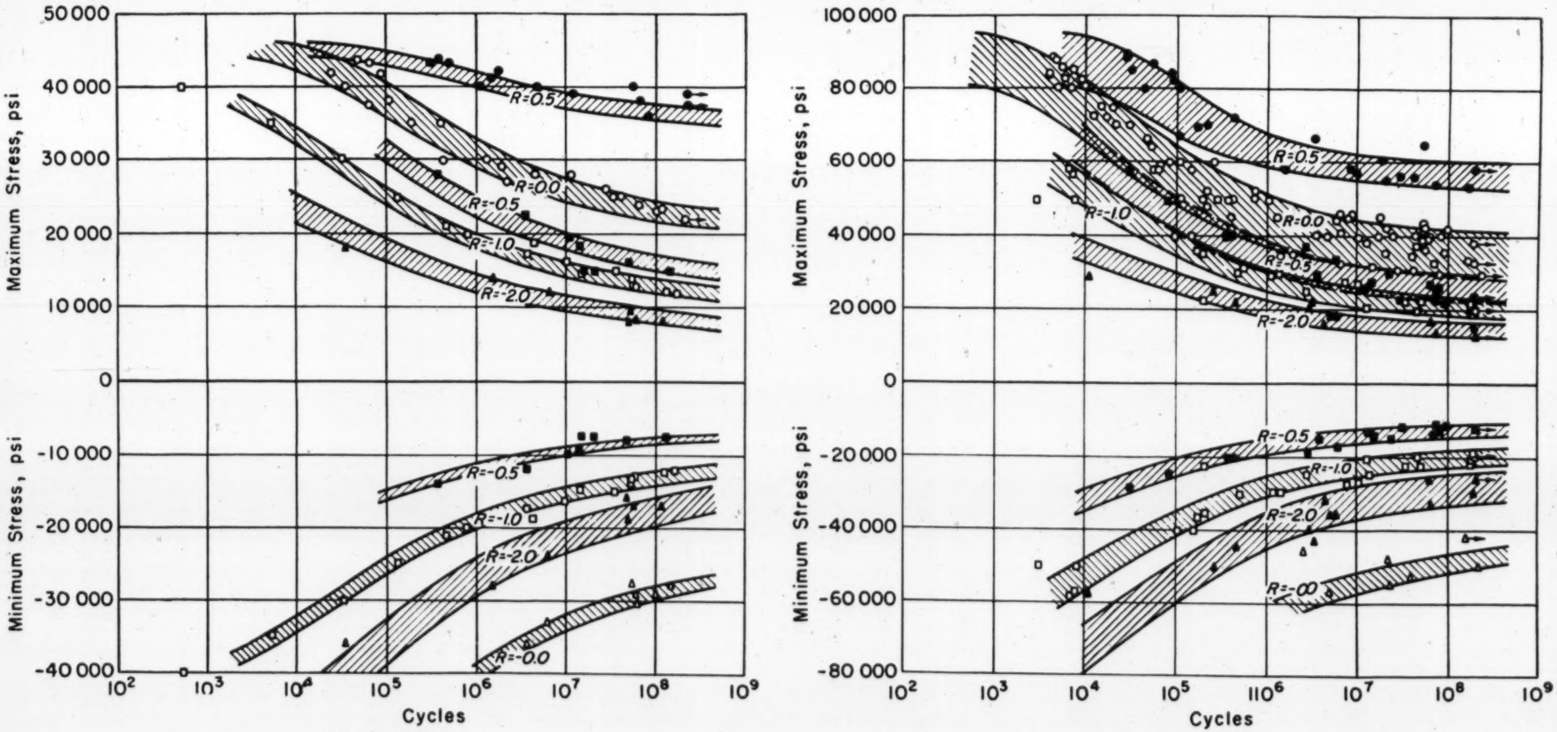
[3] R. L. Templin, "The Fatigue Properties of Light Metals and Alloys," *Proceedings*, Am. Soc. Testing Mats., Vol. 33, Part II, p. 364 (1933).



(*a*) 2014-T6



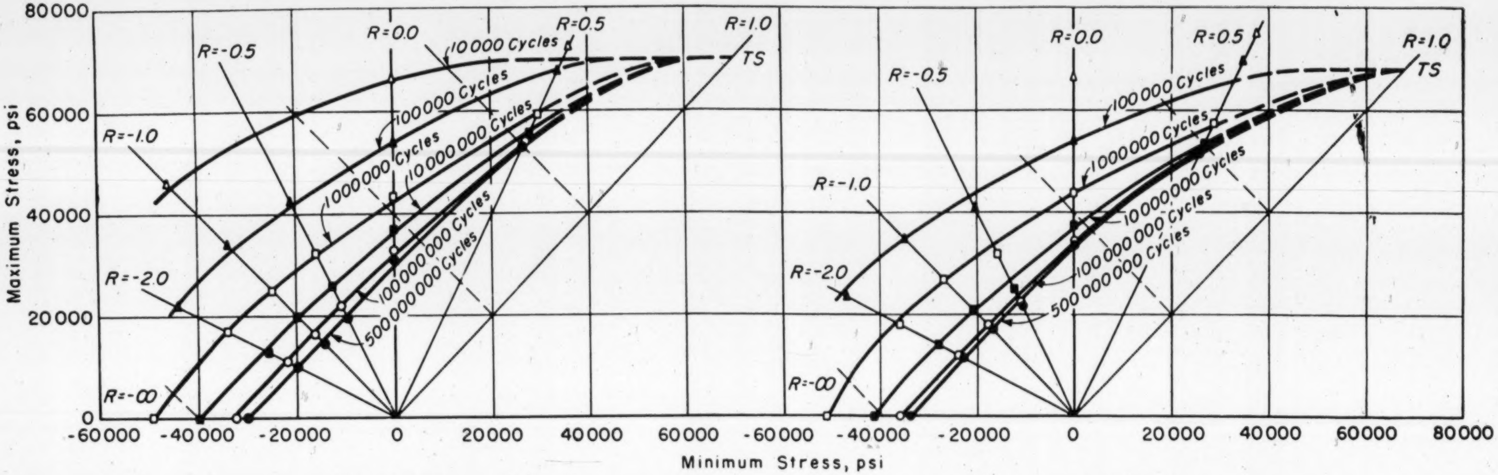
(*b*) 2024-T4



(*c*) 6061-T6

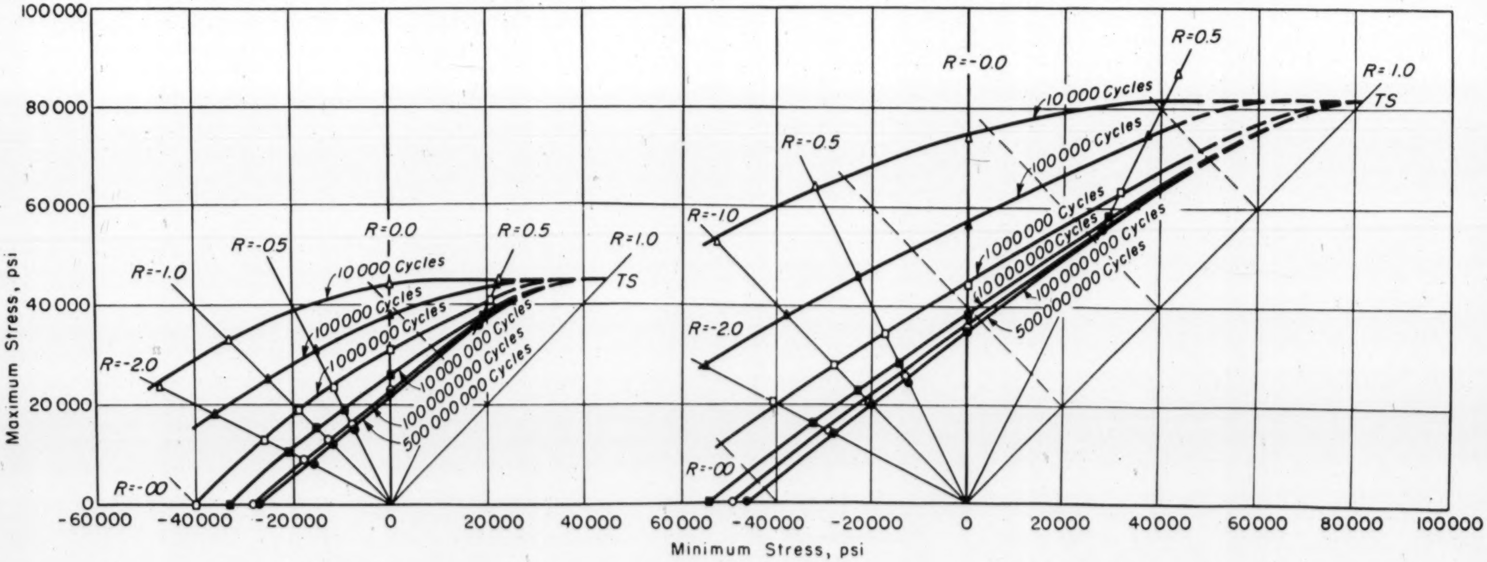
(*d*) 7075-T6

Fig. 1.—Axial-Stress Fatigue Bands for Several Structural Aluminum Alloys.



(*a*) 2014-T6

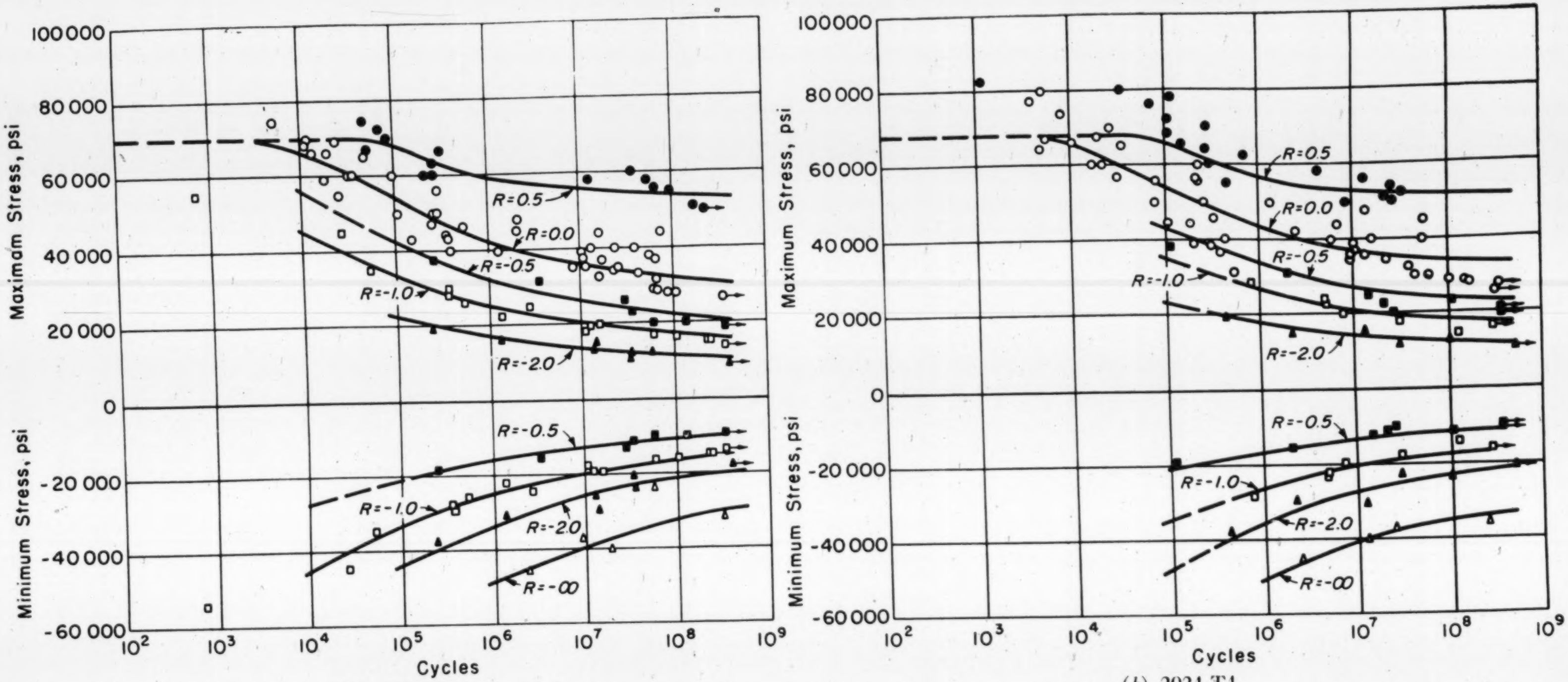
(*b*) 2024-T4



(c) 6061-T6

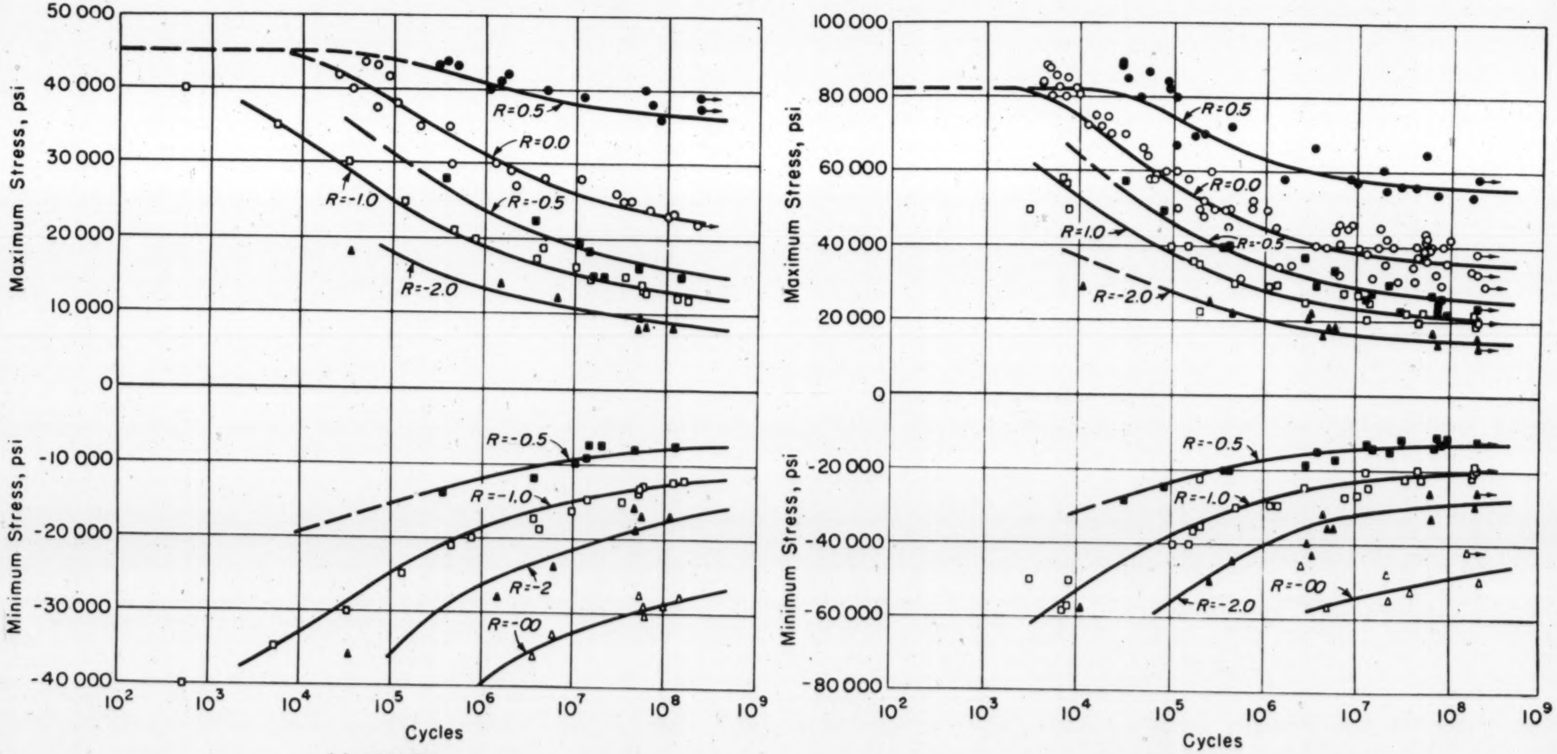
(d) 7075-T6

Fig. 2.—Modified Goodman Diagrams for Several Structural Aluminum Alloys.



(*a*) 2014-T6

(*b*) 2024-T4



(*c*) 6061-T6

(*d*) 7075-T6

FIG. 3.—Typical Axial-Stress Fatigue Curves for Several Structural Aluminum Alloys.

TABLE III.—TYPICAL AXIAL-STRESS FATIGUE STRENGTHS AT VARIOUS MINIMUM STRESSES FOR 2014-T6, 2024-T4, 6061-T6, AND 7075-T6 ALLOYS.

Alloy and Temper	Minimum Stress,[a] psi, in each Cycle	Approximate Maximum Stress[a] for Number of Cycles Indicated, psi					
		10 000 Cycles	100 000 Cycles	1 000 000 Cycles	10 000 000 Cycles	100 000 000 Cycles	500 000 000 Cycles
2014-T6......	−40 000	+49 000	+27 000	+11 000	0	...	...
	−35 000	+52 000	+31 000	+16 000	+5 000	...	...
	−30 000	+55 000	+35 000	+21 000	+10 000	+3 000	0
	−25 000	+57 000	+39 000	+25 000	+15 000	+8 000	+5 000
	−20 000	+59 000	+42 000	+29 000	+20 000	+13 000	+10 000
	−15 000	+61 000	+45 000	+33 000	+24 000	+18 000	+15 000
	−10 000	+63 000	+48 000	+36 000	+28 000	+23 000	+20 000
	−5 000	+65 000	+51 000	+39 000	+32 000	+28 000	+25 000
	0	+66 000	+54 000	+42 000	+36 000	+32 000	+30 000
	+5 000	+67 000	+57 000	+45 000	+40 000	+36 000	+35 000
	+10 000	...	+59 000	+48 000	+44 000	+40 000	+39 000
	+15 000	...	+61 000	+51 000	+48 000	+44 000	+43 000
	+20 000	...	+63 000	+54 000	+51 000	+48 000	+47 000
	+25 000	...	+65 000	+57 000	+54 000	+52 000	+51 000
	+30 000	...	+67 000	+60 000	+57 000	+56 000	+55 000
	+35 000	...	+68 000	+62 000	+60 000	+59 000	+58 000
2024-T4......	−40 000	...	+31 000	+15 000	+2 000	...	...
	−35 000	...	+35 000	+20 000	+7 000	+1 000	...
	−30 000	...	+38 000	+24 000	+12 000	+6 000	+4 000
	−25 000	...	+41 000	+28 000	+17 000	+11 000	+9 000
	−20 000	...	+44 000	+32 000	+21 000	+16 000	+14 000
	−15 000	...	+47 000	+35 000	+25 000	+20 000	+19 000
	−10 000	...	+49 000	+38 000	+29 000	+25 000	+24 000
	−5 000	...	+52 000	+41 000	+33 000	+30 000	+29 000
	0	...	+54 000	+44 000	+37 000	+34 000	+33 000
	+5 000	...	+56 000	+46 000	+40 000	+38 000	+37 000
	+10 000	...	+58 000	+49 000	+44 000	+42 000	+41 000
	+15 000	...	+60 000	+51 000	+47 000	+46 000	+45 000
	+20 000	...	+62 000	+53 000	+50 000	+49 000	+48 000
6061-T6......	−35 000	+32 000	+19 000	+5 000	...	...	...
	−30 000	+34 000	+22 000	+10 000	+3 000	...	...
	−25 000	+37 000	+25 000	+14 000	+8 000	+3 000	+2 000
	−20 000	+39 000	+28 000	+18 000	+12 000	+7 000	+6 000
	−15 000	+40 000	+31 000	+22 000	+15 000	+11 000	+10 000
	−10 000	+42 000	+33 000	+25 000	+19 000	+15 000	+14 000
	−5 000	+43 000	+36 000	+28 000	+23 000	+19 000	+18 000
	0	+44 000	+38 000	+31 000	+26 000	+23 000	+22 000
	+5 000	...	+40 000	+33 000	+29 000	+27 000	+26 000
	+10 000	...	+41 000	+36 000	+33 000	+31 000	+30 000
	+15 000	...	+42 000	+38 000	+36 000	+35 000	+34 000
	+20 000	...	+43 000	+41 000	+39 000	+38 000	+37 000

TABLE III.—(*Continued*).

Alloy and Temper	Minimum Stress,[a] psi, in each cycle	Approximate Maximum Stress[a] for Number of Cycles Indicated, psi					
		10 000 Cycles	100 000 Cycles	1 000 000 Cycles	10 000 000 Cycles	100 000 000 Cycles	500 000 000 Cycles
7075-T6......	−55 000	+52 000	+28 000	+10 000	0	...	...
	−50 000	+55 000	+31 000	+13 000	+3 000	0	...
	−45 000	+58 000	+34 000	+17 000	+7 000	+4 000	+1 000
	−40 000	+60 000	+37 000	+20 000	+11 000	+8 000	+5 000
	−35 000	+62 000	+39 000	+23 000	+14 000	+11 000	+9 000
	−30 000	+64 000	+42 000	+27 000	+18 000	+15 000	+13 000
	−25 000	+66 000	+45 000	+30 000	+21 000	+18 000	+16 000
	−20 000	+68 000	+47 000	+33 000	+25 000	+22 000	+20 000
	−15 000	+70 000	+50 000	+36 000	+28 000	+26 000	+24 000
	−10 000	+72 000	+52 000	+39 000	+31 000	+29 000	+27 000
	−5 000	+74 000	+55 000	+42 000	+35 000	+33 000	+31 000
	0	+75 000	+57 000	+45 000	+38 000	+36 000	+35 000
	+5 000	+76 000	+60 000	+48 000	+42 000	+40 000	+39 000
	+10 000	...	+62 000	+50 000	+45 000	+43 000	+42 000
	+15 000	...	+64 000	+53 000	+49 000	+47 000	+46 000
	+20 000	...	+67 000	+56 000	+52 000	+50 000	+49 000

[a] Plus (+) means tension; minus (−) means compression.

by proper positioning of the loading link and adjustment of the eccentric, any desired stress ratio and any desired range of stress within the capacity of the machine can be applied to a specimen. Generally, a specimen having a minimum diameter of 0.200 in. is used, and with it maximum stresses up to about 58,000 psi can be obtained. In order to test some of the higher strength alloys at higher stresses, the specimen diameter was reduced to 0.160 in.

For some of the tests at very high stresses (above the tensile yield strength), where small numbers of cycles at failure were expected, the machines were run by hand at about 60 cpm using a crank attached to one end of the drive shaft. In these high-stress tests, the deflections of the loading links were measured frequently and adjustments were made when necessary to maintain the minimum and maximum loads as nearly constant as possible throughout the tests.

Tests of the various samples were made at one or more of the following stress ratios: $R = +0.5, 0.0, -0.5, -1.0, -2.0$, and $-\infty$, where R is the ratio of the minimum to the maximum stress in each cycle. The stresses are considered algebraically, tension being positive (+) and compression negative (−).

DISCUSSION

The results of the tests that have been accumulated over the past several years are plotted in Fig. 1.

The individual test data for 2014–T6 products are plotted in Fig. 1(*a*). Maximum stress *versus* number of cycles for stress ratios of +0.5, 0.0, −0.5, −1.0, and −2.0 are shown in the upper part of Fig. 1.(*a*) while minimum stress *versus* number of cycles for stress ratios of −0.5, −1.0, −2.0, and $-\infty$ are shown in the lower part. Since all of the points representing maximum stress for a stress ratio of $-\infty$ would fall on the line for zero stress, it is necessary to plot minimum stress to show the scatter encountered. To complete the picture, the minimum stresses for all negative stress ratios are shown.

TABLE IV.—TYPICAL AXIAL-STRESS FATIGUE STRENGTHS AT VARIOUS MEAN STRESSES FOR 2014-T6, 2024-T4, 6061-T6, AND 7075-T6 ALLOYS.

Alloy and Temper	Mean (Steady) Stress,[a] psi	Approximate Reversed (Alternating) Stress[a] for Number of Cycles Indicated, psi					
		10 000 Cycles	100 000 Cycles	1 000 000 Cycles	10 000 000 Cycles	100 000 000 Cycles	500 000 000 Cycles
2014-T6......	−20 000	...	±32 000	±25 000	±20 000	±17 000	±15 000
	−10 000	±45 000	±33 000	±26 000	±20 000	±17 000	±15 000
	0	±45 000	±33 000	±25 000	±20 000	±17 000	±15 000
	+10 000	±43 000	±31 000	±24 000	±19 000	±16 000	±15 000
	+20 000	±40 000	±29 000	±21 000	±18 000	±16 000	±15 000
	+30 000	±35 000	±26 000	±19 000	±16 000	±15 000	±14 000
	+40 000	±29 000	±22 000	±16 000	±14 000	±13 000	±13 000
	+50 000	±20 000	±18 000	±13 000	±12 000	±11 000	±11 000
2024-T4......	−20 000	...	...	±27 000	±21 000	±18 000	±17 000
	−10 000	...	±36 000	±28 000	±21 000	±18 000	±17 000
	0	...	±35 000	±27 000	±21 000	±18 000	±17 000
	+10 000	...	±33 000	±25 000	±20 000	±18 000	±17 000
	+20 000	...	±30 000	±22 000	±18 000	±17 000	±16 000
	+30 000	...	±26 000	±19 000	±16 000	±15 000	±15 000
	+40 000	...	±21 000	±15 000	±13 000	±12 000	±12 000
	+50 000	...	±16 000	±11 000	±10 000	±9 000	±9 000
6061-T6......	−20 000	...	...	±20 000	±17 000	±15 000	±14 000
	−10 000	...	...	±20 000	±16 000	±14 000	±13 000
	0	±33 000	±25 000	±19 000	±15 000	±13 000	±12 000
	+10 000	±29 000	±22 000	±17 000	±14 000	±12 000	±11 000
	+20 000	±24 000	±18 000	±14 000	±12 000	±10 000	±10 000
	+30 000	±15 000	±13 000	±10 000	±9 000	±9 000	±8 000
7075-T6......	−20 000	...	...	±32 000	±26 000	±24 000	±23 000
	−10 000	...	±41 000	±30 000	±25 000	±23 000	±21 000
	0	±53 000	±38 000	±28 000	±23 000	±21 000	±20 000
	+10 000	±50 000	±35 000	±26 000	±21 000	±20 000	±19 000
	+20 000	±46 000	±32 000	±23 000	±19 000	±18 000	±17 000
	+30 000	±41 000	±28 000	±21 000	±17 000	±16 000	±15 000
	+40 000	±36 000	±25 000	±18 000	±15 000	±14 000	±14 000
	+50 000	±29 000	±21 000	±15 000	±13 000	±12 000	±12 000
	+60 000	±22 000	±17 000	±12 000	±10 000	±10 000	±10 000

[a] Plus (+) means tension; minus (−) means compression.

Similarly the data for 2024-T4 products are shown in Fig. 1 (*b*), those for 6061-T6 are shown in Fig. 1(*c*), and those for 7075-T6 are shown in Fig. 1(*d*).

It has not been practical to make a complete series of tests of each sample at all stress ratios; for some samples and some stress ratios, more data are available than for others. This has had an effect on the widths of the bands. For example, the larger number of results for a stress ratio of zero has made the bands for this ratio proportionately wider than the others.

Scatter bands for each stress ratio were drawn, as shown in Fig. 1, to include most of the data and, at the same time, to allow somewhat for inconsistencies. In determining the shapes of the bands, consideration has been given not only to the data for a specific ratio, but also to the data for other ratios, so as to make the bands compatible with each other. Where there were sufficient data, the high stress ends of some of the bands were drawn to the range of actual tensile strengths of the samples included in that band.

From the family of bands for each alloy, the median points of the stress range at various numbers of cycles were determined and plotted in the form of modified Goodman diagrams, as shown in Fig. 2. Average curves were then drawn for various numbers of cycles, the upper ends of the curves being drawn to the typical tensile strengths of the alloys rather than to the medians of the actual tensile strengths.

From the Goodman diagram curves, typical *S-N* curves have been drawn for different stress ratios of the respective alloys in Fig. 3. The actual individual test data for the products of each of the four alloys, originally shown in Fig. 1, are again shown in Fig. 3.

To facilitate interpretation of the data for design purposes, three methods of tabulating the results are presented in Tables II, III, and IV:

First Method.—Fatigue strengths for various stress ratios at various numbers of cycles are presented in Table II. These values are obtained from the Goodman diagrams by locating the intersection of a constant-cycle line with a constant stress-ratio line and reading maximum stress from the ordinate scale or minimum stress from the abscissa scale. The values given in Table II for all stress ratios except $R = -\infty$ are maximum stresses. For $R = -\infty$ the maximum stress is always zero; hence, minimum stress values are given.

Second Method.—Fatigue strengths for various minimum stresses at various numbers of cycles are presented in Table III. These values are obtained by locating the intersection of a constant cycle line with a constant minimum stress line and reading maximum stress from the ordinate scale.

Third Method.—Fatigue strengths for various mean stresses at various numbers of cycles are presented in Table IV. In Fig. 2, lines of constant mean stress are represented by the dashed lines drawn parallel to the -1.0 stress-ratio line and their values are read on either stress scale for the points where they intersect the $+1.0$ stress-ratio line. The fatigue strengths in Table IV are maximum alternating stresses that can be withstood for a given number of cycles at various mean stresses. The maximum alternating stress for a stated number of cycles is obtained by first determining the maximum stress at the point of intersection of the mean stress (dashed line) and the curve for that number of cycles, and then subtracting the mean stress from the maximum stress.

SUMMARY

With the proper selection of stress ratios and through the use of scatter bands and modified Goodman diagrams, a basis has been provided for final tabulation of average or typical axial-stress fatigue strengths. By this means, typical fatigue strengths pertaining to various conditions of stress ratio, minimum stress, and mean stress have been determined for the more important structural aluminum alloys, 2014-T6, 2024-T4, 6061-T6, and 7075-T6. From the Goodman diagrams, limiting stresses can be selected for conditions other than those shown in the tables.

DISCUSSION

Mr. J. T. Ransom.[1]—I am very much interested in the Goodman diagrams presented, particularly in view of the usual arguments that are advanced for the improvement of fatigue strength by prestressing operations.

The point I would like to make is that these data indicate that for the aluminum alloys the Goodman diagram tends to converge as you go into the compression region. This means that if you put compressive prestress into the surface of aluminum components by shot peening, you really are not doing yourself any good because you do not increase the safe range of stress that can be tolerated.

This is not what we have found in ferrous materials. We have observed that the range of safe stress continues to diverge the more compressive the mean stress. The natural question that arises, then, is whether the behavior of the aluminum material is really different from that of the ferrous material, or whether the difference is a result of superimposed bending stresses in the tests of the aluminum specimens.

I would like to ask the authors whether they feel they have eliminated bending stresses in their axial fatigue tests.

Mr. F. M. Howell (*author*).—The design of the machines used in our tests is such that any bending stresses that are present undoubtedly are very small. Tests made with other types of axial-stress fatigue machines have given approximately the same results. This, of course, does not prove that bending stresses are absent in our tests, for it is practically impossible to completely eliminate bending stresses in any axial-stress machine that operates in both tension and compression.

With regard to the question regarding the shape of the part of the Goodman diagram representing conditions in which the mean stress is a compressive stress, it may be that the curves were not drawn quite as carefully as they should have been, but we must also recognize that our tests for a ratio of minus infinity were quite limited. The range probably does not decrease, but remains about the same as for a ratio of minus two.

Mr. Ransom's comments concerning the compression region of the diagram were made in trying to determine whether shot peening could be beneficial. Shot peening of wrought aluminum alloys is being used commercially to obtain increased fatigue life. As in the shot peening of ferrous materials, the conditions of shot peening must be carefully established and controlled in order to obtain beneficial instead of harmful effects.

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[1] Engineering Research Laboratory, Engineering Department, E. I. du Pont de Nemours & Co., Inc., Wilmington, Del.

BEHAVIOR OF Ti-75A TITANIUM ALLOY UNDER REPEATED LOAD*

By R. G. Crum[1] and E. D'Appolonia[1]

Synopsis

This paper deals with an investigation of Ti-75A titanium alloy. R. R. Moore rotating-beam specimens were subjected to complete reversals of cyclic bending. Emphasis is placed on the pseudo-elastic behavior of the material when stressed well above the usual linear-elastic limit as found under static loading. At these high stresses the initial strains, measured by mid-span deflection, were consistent with strains taken from a curve that is the extension of the linear portion of the static stress-strain curve. Depending on the stress level, a number of applications of load was necessary before the dynamic strains became equal to the actual plastic strains taken from the static curve. Irrespective of the stress level, no damage, as measured by change in number of cycles to failure, was observed as long as the specimen was acting in this pseudo-elastic manner.

Effects of internal heating and strain rate on the fatigue behavior of the material were studied.

Past Studies.—A delay action in plastic deformation upon an application of a dynamic load to a material has been described in the literature (**1, 2, 3, 4, 5**).[2] Wood and Head (**6**) showed that dynamic strains in a material stressed above its usual linear-elastic range do not follow the plastic stress-strain relation found under static loading. Rather, the dynamic strains are in agreement with strains taken from a curve which is the extension of the linear-elastic portion of the static stress-strain curve. They attribute this pseudo-elastic behavior of the material to the delay in incidence of slip following sudden application of a stress. When a stress was applied for a period longer than the delay period, they observed that a slip of the material produced strains associated with unidirectional plastic flow. If the stress was applied for a period shorter than the delay period, relatively little slip occurred; and if the stress was quickly reversed again, only small amounts of slip occurred, these being in the direction opposite the first. Dolan and Work (**7**) showed that the elastic region of a material is increased appreciably by strain rate effects. Hunter and Fricke (**8**) disclosed that there is no appreciable slip in the initial stages of the finite-life of a specimen subjected to a repeated load.

These investigations seem to indicate that rapidly reversed loading, as in fatigue testing, does not allow time for the material to yield during the initial cycles of loading. During this period the material behaves elastically even at stress levels above the usual linear-elastic limit as found under static loading. In the initial cycles of loading, small amounts of damage occur with each cycle of load. As the damage accumulates and grows with repeated load applications, the behavior of the material becomes plastic—severe damage and failure ensue. It appears that there is a transition from pseudo-elastic to plastic behavior and that this transition defines the threshold of the region of severe damage. The number of cycles during which a material exhibits this pseudo-elastic behavior depends on the speed and conditions of testing, the geometry of the specimen, and the structure of the material.

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* Presented at the Fifty-eighth Annual Meeting of the Society, June 26–July 1, 1955.

[1] Research Assistant, and Associate Professor in Civil Engineering, respectively, Carnegie Institute of Technology, Pittsburgh, Pa.

[2] The boldface numbers in parentheses refer to the list of references appended to this paper, see p. 977.

TABLE I.—MECHANICAL PROPERTIES OF Ti-75A, TITANIUM ALLOY (**9**).

Rockwell hardness, C scale	23 to 24
Modulus of elasticity in tension, psi	15.5×10^6
Yield strength—0.2 per cent offset (tension), psi	65 000
Tensile strength, psi	86 000
Nominal strain at fracture (2-in. gage length), in. per in.	0.33
True ultimate strength (tension),[a] psi	133 000
True strain at fracture,[b] in. per in.	0.70
Reduction area at fracture, per cent	54.6
Modulus of elasticity in compression, psi	17 000 000

[a] The total load at fracture divided by the instantaneous area at fracture.

[b] In the plastic region it is assumed that the volume remains constant and therefore the strain is given by the natural logarithm of the ratio of the original cross-sectional area to the instantaneous cross-sectional area.

Present Study.—The present study was directed to investigate the pseudo-elastic behavior of unnotched specimens of Ti-75A titanium alloy. Complete reversal rotating-beam fatigue data were obtained at 30, 200, 400, 900, 1800, and 10,000 rpm with and without a coolant bath. Continuous strip recordings of (1) mid-span deflection, a measure of the strains in the material, and (2) energy input necessary to maintain the specimen at constant speed, a measure of the internal energy loss of the material, were made at 200, 400, and 900 rpm without coolant. Damage, measured by change in number of cycles to failure, was correlated with cycles of loading at different stress levels. This study of damage was made at 400 rpm without coolant.

MATERIAL USED

All fatigue tests were conducted on the one material, Ti-75A titanium alloy. The chemical composition for the alloy included 0.025 carbon, 0.061 nitrogen, 0.19 iron, and the remaining percentage titanium. Table I summarizes the mechanical properties of the alloy.

PROCEDURE AND DATA

Apparatus:

Continuous strip recordings of mid-span deflection were made with a deflection gage consisting of a thin reed to which an SR-4 electrical strain gage was attached. Measurements of mid-span deflection were made to an accuracy of 0.0005 in. without touching the rotating specimen. This was done by calibrating the mid-span deflection with the deflection of a point on the specimen housing.

To measure the energy input necessary to maintain a specimen at constant speed, the power from the motor to the specimen was transmitted through a flexible bar from which bending strains, a measure of torque, were continuously recorded. Details of the apparatus are given in an earlier paper (**9**).

There is no internal energy loss, except for minor hysteresis losses, when each fiber of a specimen stressed in pure bending has a linear stress-strain relation. This is valid for the usual linear-elastic region of the stress-strain curve and in that region where the material exhibits a pseudo-elastic behavior. No torque except that necessary to overcome friction, windage, etc., is needed to maintain the specimen at constant speed. However, when the specimen begins to deflect plastically an additional torque is necessary to turn the specimen; thus there is an increase in the energy input required to maintain the specimen at constant speed. The energy associated with the increase in deflection from plastic behavior is not stored in the system but is dissipated as heat. Since the increase in torque supplies energy to the system at the same rate that heat is dissipated to the surroundings, the torque is a measure of the internal energy loss within the material due to plastic distortion under repeated load.

Observed Delay in Plastic Distortion:

Figure 1 shows the observed mid-span deflection of a specimen plotted as a function of the nominal bending stress. The specimens were placed in the fatigue machine and loaded statically. The open circles of Fig. 1 give the initial mid-span deflection when the stress is increased suddenly, but without impact, from zero to a particular stress level. The initial mid-span deflection when the stress was increased from zero to a value beyond the elastic limit agreed with the deflection computed from linear theory. After this temporary pseudo-elastic behavior, the deflection increased slowly to the static-plastic deflection indicated by the solid circles in Fig. 1.

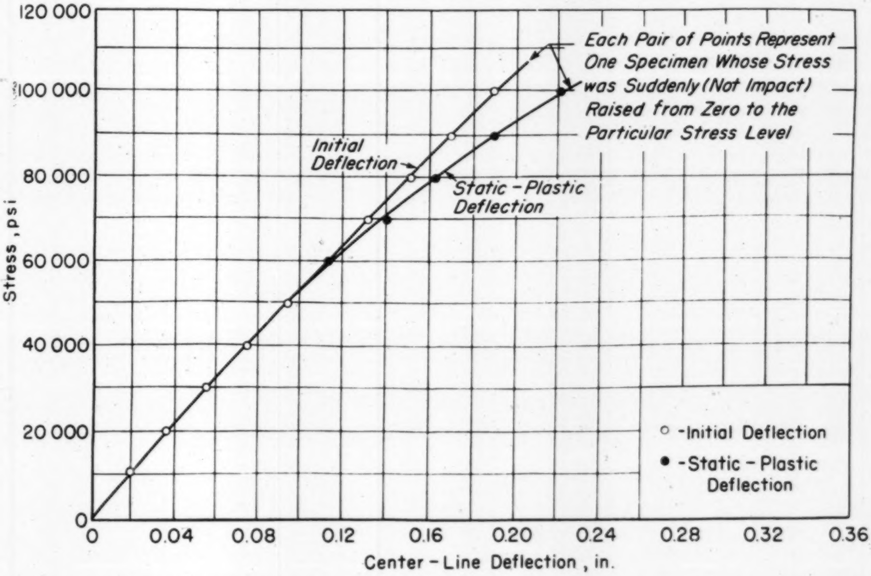

Fig. 1.—Mid-Span Deflection Under Static Load as a Function of Stress—Specimens Held in Regular Position for Fatigue Loading.

The behavior of a fatigue specimen was considered pseudo-elastic if the mid-span deflection during fatigue testing was less than the static-plastic deflection shown in Fig. 1 and plastic if the mid-span deflection was equal to or greater than the static-plastic deflection.

S-N Data:

Fatigue data obtained under complete

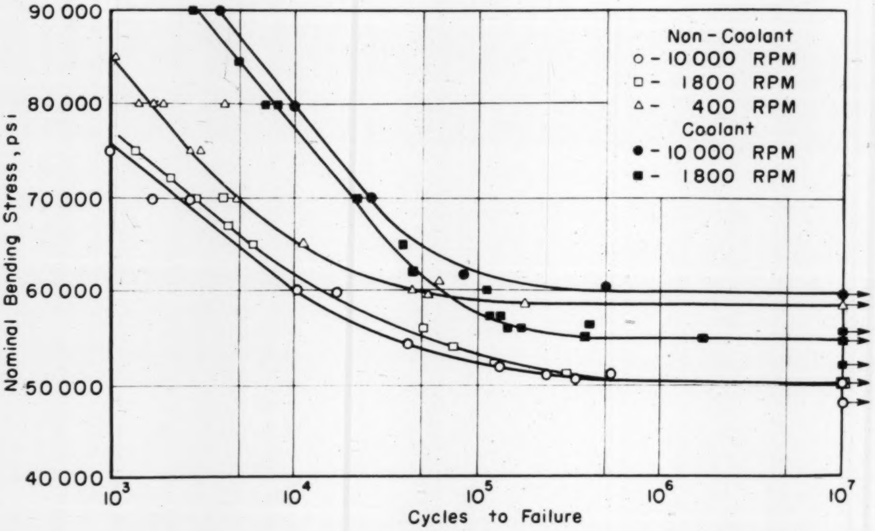

FIG. 2.—Summary of *S-N* Diagrams for Ti-75A Titanium Alloy Tested at Different Speeds with and Without Coolant.

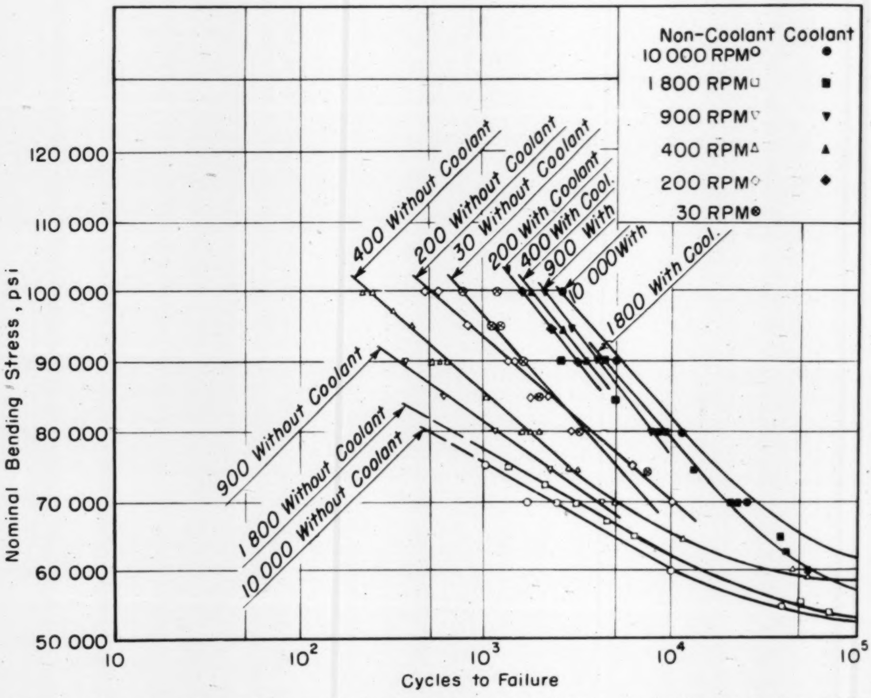

FIG. 3.—Upper Portions of Stress-Cycles Curves for Ti-75A Titanium Alloy Tested at Different Speeds with and Without Coolant.

stress reversal and for different testing speeds with and without coolant are shown in Fig. 2. Figure 3 gives the upper portions of the S-N curves. The ordinates to these curves as well as all fatigue curves given in this paper are nominal bending stresses computed from linear theory. In this work, stress will imply nominal bending stress.

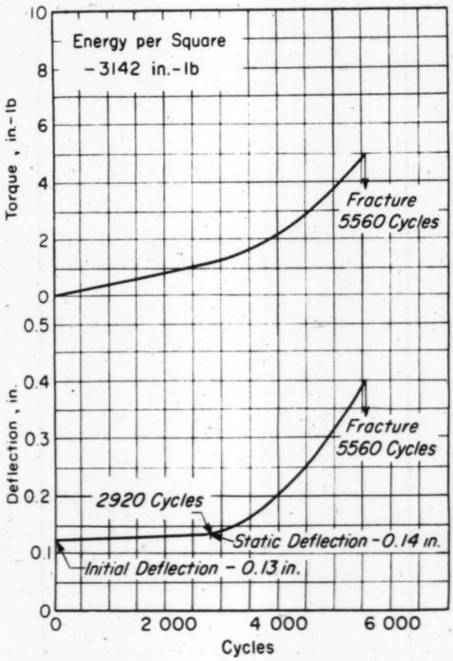

Fig. 4.—Comparison of Torque and Deflection Records for Nominal Bending Stress of 70,000 psi for Ti-75A Titanium Alloy Tested at 400 rpm Without Coolant.

Strain rate and internal heating effects on the fatigue behavior of Ti-75A were found. The fatigue behavior of the material is predominantly influenced by internal heating when tests are conducted without coolant. Without coolant the finite-life of a specimen is decreased with increased speed of testing. The influence of internal heating on fatigue behavior was practically eliminated when tests were conducted with coolant. The S-N curves (Figs. 2 and 3) for coolant tests are all grouped in a narrow band, showing no apparent strain-rate effect in the finite-life range.

Deflection and Torque Data:

Figure 4 is a reproduction of the deflection and torque recordings for a specimen tested at 70,000 psi at a speed of 400 rpm without coolant. The initial deflection agrees with the initial deflection shown for static loading in Fig. 1. The deflection did not reach the static-plastic deflection of Fig. 1 until 52 per cent (2920 cycles) of finite-life of the specimen had elapsed. At this number of cycles both the deflection and torque increased rapidly. These data are typical of those found for all specimens tested. The curves show that the material has a pseudo-elastic behavior during early stages of repeated loading.

Figure 5 gives curves of cycles to failure and cycles to reach static-plastic deflection as a function of nominal bending stress for specimens tested at 400 rpm without coolant. Both curves are straight lines on semi-log paper. Figure 6 shows the total energy to failure as a function of nominal bending stress for specimens tested at 400 rpm without coolant. The energy input is measured by the applied torque times the angular movement through which the torque acts. The total energy is obtained by summing the area under the torque-cycles curve and multiplying by 2 π radians per cycle.

Damage:

Damage of a specimen was measured by change in total number of cycles to failure. It was desired to establish the relative rate at which damage occurs during the initial pseudo-elastic period compared to the rate at which damage occurs when the specimen deforms plastically. To do this, specimens were first

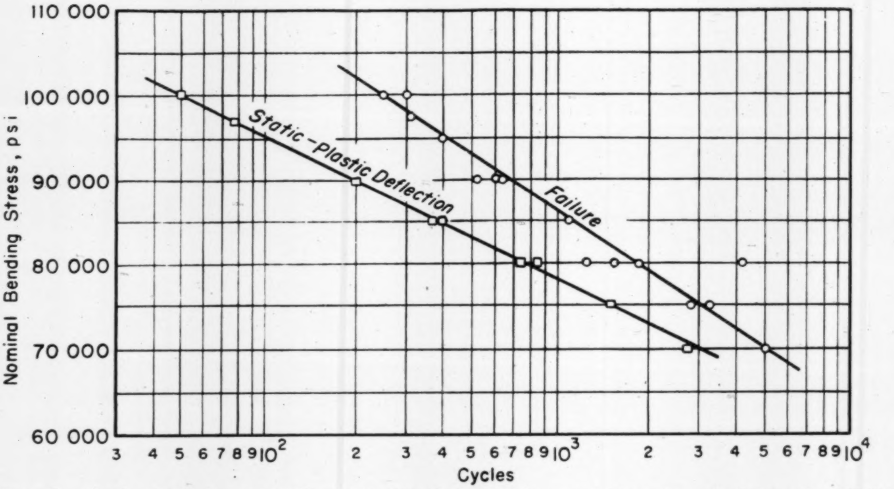

FIG. 5.—Cycles to Failure and Cycles to Static Deflection as a Function of Stress for Ti-75A Titanium Alloy Tested at 400 rpm Without Coolant.

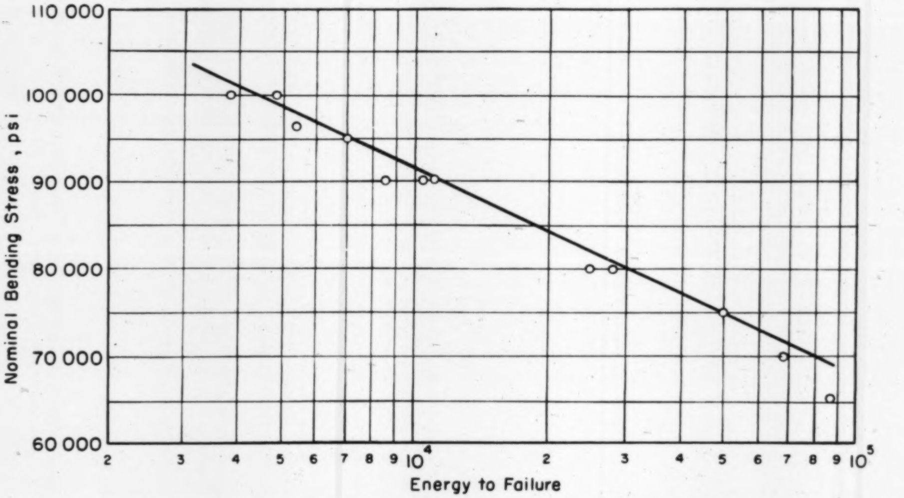

FIG. 6.—Energy to Failure as a Function of Stress for Ti-75A Titanium Alloy Tested at 400 rpm Without Coolant.

subjected to cyclic prestresses higher or lower than the normal stress level at which the specimen was to be tested to failure. The prestressing was done at 90,000 and 100,000 psi. The amount of prestress to which the specimens were subjected is given by the ratio of the number of cycles of prestress to the number of cycles to reach the static-plastic deflection at the prestress level. This ratio is defined by N_o/N_s. Tests were conducted at N_o/N_s ratios of 0.8, 1.2, 1.5, and 1.8. The specimens were then tested to failure at normal stress levels between 70,000 and 100,000 psi.

Figure 7 gives the results of cyclic

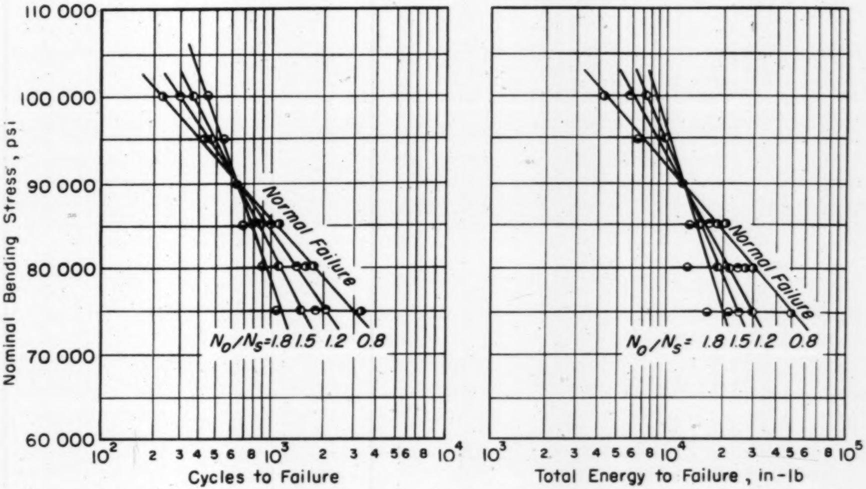

FIG. 7.—Cycles to Failure and Total Energy to Failure as a Function of Normal Stress for Cyclic Prestress at 90,000 psi for Ti-75A Titanium Alloy Tested at 400 rpm Without Coolant.

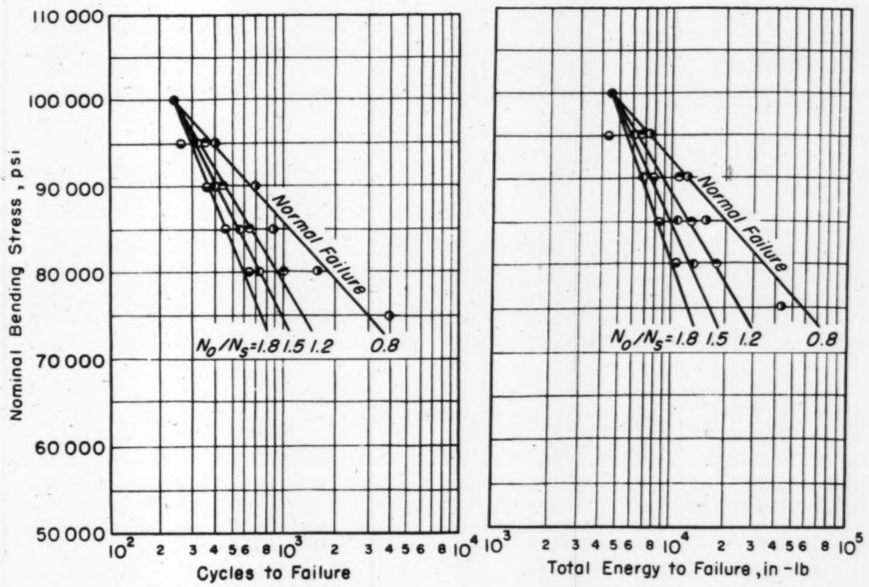

FIG. 8.—Cycles to Failure and Total Energy to Failure as a Function of Normal Stress for Prestress at 100,000 psi for Ti-75A Titanium Alloy Tested at 400 rpm Without Coolant.

prestress at 90,000 psi. The curves marked "normal failure" were reproduced from the failure curves in Figs. 5 and 6. The failure curve for the ratio N_o/N_s equal to 0.8 coincides with the normal failure curve, indicating no change in finite-life or total energy to failure. For ratios of N_o/N_s greater than 1.0, the failure curves do not coincide with the normal failure curve. The curves of total cycles to failure are straight lines pivoting about the cycles to failure at 90,000 psi.[3] Figure 7 shows identical relations between N_o/N_s and per cent reduction in cycles to failure and N_o/N_s and per cent reduction in total energy to failure.

Figure 8 shows that test data for prestress at 100,000 psi are similar to that described for prestress at 90,000 psi.

DISCUSSION OF OBSERVATIONS

The general fatigue behavior of Ti-75A titanium alloy and the effects of internal heating and strain rate as shown in Figs. 2 and 3 tend to translate the *S-N* curves and to change their slopes and alter the endurance limit. The behavior of specimens tested without the water coolant is predominantly influenced by internal heating. Specimens tested at 10,000 rpm glowed red hot at fracture. This was observed previously with several titanium alloys (**10, 11, 12**). Specimens tested at 30 rpm had the longest finite-life; no heating effects were apparent, and the specimens were not warm. The *S-N* curve at this speed had the steepest slope. At 200 and 400 rpm the specimens were warm, and at speeds of 900 rpm and above, the specimens could not be touched during the latter portion of their finite-life. The effects of internal heating were more pronounced at the higher stresses, as evidenced by the flatter slope of the upper portion of the *S-N* curves at testing speeds of 200 and 400 rpm as compared to the slope of the curve obtained at 30 rpm. The slopes of the *S-N* curves at 900, 1800, and 10,000 rpm are the same. However, they are not so steep as the curves obtained at testing speeds of 200 and 400 rpm. The reduction in finite-life at any stress level decreases with increase in testing speed. This implies a "leveling-off" effect of internal heating at the faster speeds.

The effect of internal heating on the fatigue behavior of titanium specimens was greatly reduced when tests were conducted with a water coolant. The shift of the *S-N* curves for different testing speeds indicates the effect of strain rate on the fatigue behavior of the material when internal heating is controlled. The endurance limit at 1800 rpm was 5000 psi less than at 10,000 rpm, indicating a considerable strain-rate effect. However, the *S-N* curves at stress levels above 70,000 psi were grouped together indicating little strain-rate effect at high stresses.

Damage.—The curves in Fig. 4 show a pronounced increase in slope as the deflection reaches the static-plastic value of that shown in Fig. 1 at 70,000 psi. With additional cycles of stress, there is a rapid increase in the ordinate to the deflection and torque curves. This increase with cycles of stress indicates the rate at which plastic distortion and damage ensue, and the rate at which energy must be supplied to compensate for the internal energy of distortion that is dissipated as heat.

In Fig. 5, the curve showing the number of cycles to reach static-plastic deflection denotes the limit of the pseudo-elastic behavior of the material under repeated load. Figures 7 and 8 give the results for specimens prestressed for different numbers of cycles of stress up to and beyond the static-plastic deflection curve of Fig. 5. For specimens cyclically prestressed to ratios of N_o/N_s less than 1.0 and tested to failure at the normal stress, there was no essential difference in the total number of cycles to failure as compared with cycles to failure for specimens tested entirely at the normal stress level. A similar comparison was found for total energy to failure. However, there was a change in the total number of cycles to failure for specimens cyclically prestressed to ratios of N_o/N_s greater than 1.0. The data of Figs. 7 and 8 establish the limit of pseudo-elastic behavior as the threshold of severe damage.

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[3] The curves must all pass through the point of normal failure at 90,000 psi since the prestress and normal stress have the same magnitude.

Summary and Conclusions

The investigation shows that Ti-75A titanium alloy exhibits a pseudo-elastic behavior during early stages of repeated loading at stresses well above the usual elastic limit. The initial strains are linear-elastic. This suggests that the bending stress computed from linear theory is the actual stress during the early stages of repeated loading.

For the first portion of the finite-life of a specimen, the deflection increases slowly with repeated load applications. Once the mid-span deflection becomes equal to the plastic deflection as found under static load, it increases rapidly and failure ensues. The number of cycles at which the static-plastic deflection is reached has been established as the threshold of severe damage at that particular stress level. Tests show that there is no measurable effect on the finite-life of a specimen when it is cyclically prestressed at various stress levels for a number of cycles less than that required to produce static-plastic deflection. The finite-life of a specimen is changed if it is cyclically prestressed a number of cycles beyond the threshold of severe damage.

Tests made at different speeds with and without a water coolant showed that strain rate and internal heating influence the fatigue behavior of Ti-75A titanium alloy. Internal heat from plastic distortion was the most significant factor which influenced the fatigue behavior of the alloy. A large spread in the failure curves was found at testing speeds between 30 and 10,000 rpm. Specimens which were water cooled to dissipate the internal heat showed small spread in the failure curves for the different speeds of testing that were studied.

Acknowledgment:

The research was conducted under the auspices of Watertown Arsenal under Contract No. DA-36-061-ORD-362, and the project was under the technical supervision of the Applied Mechanics Branch of the Watertown Arsenal Laboratories. The authors thank F. T. Mavis, Head of the Department of Civil Engineering, Carnegie Institute of Technology, who gave many helpful criticisms and suggestions.

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DISCUSSION

Mr. Clarence R. Smith.[1]—Since the fatigue machine was of a rotating-beam type, would some of these higher initial loads have induced some permanent set which would affect the fatigue life at subsequent lower levels? We could not compare this with axial loading. The specimen will be permanently deformed after loading beyond the proportional limit. Subsequent testing at lower levels would be done with a crooked specimen, thus inducing higher than calculated bending stresses due to inertia effects.

Mr. B. J. Lazan.[2]—Much of the analysis presented by the authors is based on the static plastic deflection, and I should like to inquire about the justification for this criterion.

First of all, what strain rate was used in determining the static stress-strain properties? Secondly, how sensitive is the plastic deflection to strain rate for the material investigated? Finally, is there any fundamental reason the authors would give for making their analysis in terms of the static plastic deflection?

Mr. T. J. Dolan.[3]—The behavior pointed out in Fig. 8 is not entirely peculiar to titanium alloys but has been observed at the University of Illinois in static tests of beams and torsion members of low-carbon steel.

In these instances, the initial static deflections increased with time and were exceeded by amounts of very large magnitude when the loads were left on for periods of 24 to 48 or 72 hr. In some instances, the plastic deformations, which initially were very small, became as much as three times as large after having been loaded for a period of two days.

As Mr. D'Appolonia has mentioned, the ordinates plotted on his *S-N* curves are not stresses (even though so labeled). These values were computed by the ordinary flexure formula, which is valid only below the elastic strength. For the titanium tested the elastic strength was somewhere around 50,000 psi, whereas most of the data were obtained at (unknown) stresses above this level. There is good evidence that the same sort of heating and increased deflections occur in steels and other metals when one tests at these extremely high loading levels. At these high overloads, however, there is considerable doubt as to the significance of the data for application to design where the stresses must be kept below the elastic strength.

Messrs. E. D'Appolonia and R. G. Crum (*authors' closure*).—With reference to Mr. Smith's comments, the specimens were not prestrained before placing in the fatigue machine. The load was applied while the specimen was rotating. Deflection observations indicated that the material behaved pseudo-elastically in the early stage of loading. No observable permanent deformation occurred during this period. Specimens cyclically loaded a sufficient number of times to produce damage and then unloaded fully or in part were permanently deformed. Deflection tests were not conducted to ascertain the permanent deformation.

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[2] Professor of Materials Engineering, Experimental Engineering Building, University of Minnesota, Minneapolis, Minn.

[3] Research Professor of Theoretical and Applied Mechanics, University of Illinois, Urbana, Ill.

The behavior of deformed specimens when tested at a lower stress level as in our damage studies would be influenced by the residual stresses that were locked up within the specimen. The effect of these residual stresses on the fatigue behavior of metals was beyond the scope of this work. Stresses due to inertia effects of a permanently deformed specimen if present were negligible. A specimen rotated about a curved axis of rotation at both high and low loads. No whipping of a specimen was observed. If inertia effects of a crooked specimen were present, they would have appeared as cyclic oscillations on the deflection charts.

With reference to Mr. Lazan's questions, the static stress-strain properties were obtained with a standard testing machine, operated at about 0.01 in. per min. The influence of strain rate on the plastic deflection of a rotating-beam fatigue specimen was not investigated.

The reason the authors used the static-plastic deflection in their work is summarized as follows: Hunter and Fricke,[4] using an electron microscope to study fatigue damage, showed that slip and crack lines appeared on the surface of fatigue specimens only after a number of cycles of repeated load had been applied. We observed from continuous time records for each test load that the mid-span deflection of a specimen and the torque necessary to rotate a specimen at constant speed increased rapidly when the mid-span deflection reached a value equal to static-plastic deflection. Further we observed that specimens, tested at a high stress level for a number of cycles less than the number required to produce a mid-span deflection equal to the static-plastic deflection and then tested to failure at a lower stress level, failed at the same number of cycles as specimens tested to failure entirely at the lower stress level. This led us to believe that the number of cycles at any stress level necessary to produce a mid-span deflection equal to the static-plastic deflection shown in Fig. 1 indicated a threshold of damage.

The influence of strain rate on the fatigue behavior of titanium is shown in Fig. 3. For specimens that were not cooled, the fatigue life decreased with increasing strain rate. The influence of strain rate was not significant when the specimens were water cooled during testing.

Mr. Dolan's remarks on the pseudo-elastic nature of low-carbon steel corroborate ours. We thank each of the discussers for their comments and contributions.

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[4] M. S. Hunter and W. G. Fricke, Jr., "Metallographic Aspects of Fatigue Behavior of Aluminum," *Proceedings*, Am. Soc. Testing Mats., Vol. 54, p. 717 (1954).

THE FATIGUE PROPERTIES OF SOME TITANIUM ALLOYS*

BY A. W. DEMMLER, JR.,[1] M. J. SINNOTT,[2] AND L. THOMASSEN[2]

SYNOPSIS

A study has been made of the rotating-beam fatigue life characteristics of three commercial titanium alloys: Ti-75A, RC-130B, and RC-A-110AT, and two experimental alloys: 6 per cent aluminum, an all-alpha alloy, and 30 per cent molybdenum, an all-beta alloy. The influence of various methods of surface preparation and treatment on the fatigue life has been evaluated. X-ray diffraction, microhardness, profilometer, and metallographic techniques were utilized to evaluate the condition of the surfaces and subsurfaces that were prepared. Shot peening improves the fatigue life in the high-stress region of the *S-N* curve while grinding adversely affects the fatigue life particularly in the lower stress ranges. No correlation exists between the specimen surface roughness and the resulting fatigue life. There appears to be a correlation between the tensile strength and the stress for a given fatigue life. Marked internal heating of the Ti-75A occurred during testing; its cause has been traced in part to the presence of hydrogen in solution. The standard deviation in cycles to failure for a given stress and surface condition appears to be of the same order of magnitude as that noted in other metals.

Studies of the behavior of metals during fatigue stressing have shown that the influence of the surface on the resulting behavior can be quite marked (**1, 2**).[3] Other work has pointed out the statistical nature of fatigue testing and how, if reliable estimates of fatigue life are to be obtained, a replicate testing procedure must be followed (**3, 4**). While some studies of the fatigue properties of titanium alloys have been reported, the influence of surface conditions was believed to be quite pronounced but unknown and the data that have been reported were not from replicated specimens. For these reasons the present work was undertaken and has as a further aim the possibility of developing surface treatments which would improve the fatigue life characteristics of the alloys.

TEST MATERIALS AND TEST SPECIMEN PREPARATION

Table I gives the analyses, as supplied by the manufacturers, of the various alloys used in this investigation. Ti-75A is commercially pure titanium, RC-130B is a two phase alloy, RC-A-110AT is an all-alpha alloy. The experimental heats were an all-alpha alloy and an all-beta alloy. The specimens were made from $\frac{5}{8}$-or $\frac{1}{2}$-in. round stock supplied in the hot-rolled and annealed condition. On receipt of a given heat of an alloy, each bar was examined metallographically and hardness traverses were made on each bar to determine the homogeneity of the stock. Each bar and test specimen was coded to determine whether there were variations between or within bars on subsequent testing. Later tests proved this step unnecessary since variations of this type were negligible. Some variations in hardness across the bars as received was noted, but subsequent annealing at 1450 F in argon removed this variation which was probably due to residual stresses introduced in working the metal.

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* Presented at the Fifty-eighth Annual Meeting of the Society, June 26–July 1, 1955.

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[2] Associate Professor, and Professor, respectively, Metallurgical Engineering, University of Michigan, Ann Arbor, Mich.

[3] The boldface numbers in parentheses refer to the list of references appended to this paper, see p. 993.

TABLE I.—CHEMICAL ANALYSES OF ALLOYS, PER CENT BY WEIGHT.

Material	Heat Number	Carbon	Nitrogen	Iron	Tungsten	Hydrogen	Manganese	Aluminum
Ti-75A	L-984	0.025	0.061	0.19	......			
Ti-75A	M-270	0.04 to 0.07	0.10	0.20	0.01	0.02 to 0.05	(Oxygen = 0.20)	
RC-130B	B-3562	0.1	0.03				5.9	5.0
RC-130B	B-3134	0.1	0.02				4.4	4.1
RC-130B	B-3413	0.1	0.08				3.9	3.9
RC-A-110AT	R-30314	0.1	0.05		Tin 2.58			4.13
All-Alpha	...	0.06	0.035					5.78
All-Beta	6189	0.016	0.069			Molybdenum	29.88	
	6188	0.011	0.065			Molybdenum	30.17	

TABLE II.—MECHANICAL PROPERTIES OF ALLOYS.[a]

Material	Heat Number	Proportional Limit, psi[b]	Tensile Strength, psi	Elongation in 2 in., per cent	Reduction of Area, per cent
Ti-75A	L-984	45 000	90 520	25.5	50.9
Ti-75A	M-270	47 900	84 300	27.3	42.0
RC-130B	B-3562	124 750	157 700	17.0	44.7
RC-130B	B-3134	82 200	149 250	15.0	43.1
RC-130B	B-3413	119 000	160 000	18.0	47.0
RC-A-110AT	R-30314	124 000	138 000	16.0	40.0
All-Alpha	...	81 900	131 500	10.1	33.5
All-Beta	6188	112 000	128 750	7.8	33.2
	6189	110 000	120 000	2.0	1.0[c]

[a] Duplicate tests.
[b] SR-4 strain gages used.
[c] Fracture in gage marks. Single test.

The mechanical properties of the alloys, Table II, were determined after the argon annealing process, a treatment that was carried out on each test specimen at some time prior to fatigue testing. No significant differences, other than slight variations in grain size, existed between the microstructures of the different heats of a given alloy. The Ti-75A had considerable hydrogen present as was evidenced by the presence of line markings.

Test Specimen Preparation:

All the fatigue testing was done on R. R. Moore type rotating-beam machines. The size and shape of the test specimens used is shown in Fig. 1. The preliminary steps taken in machining all specimens consisted of cutting bars to length, drilling centers, machining to cylinders 0.500 in. in diameter, and rough machining to 0.050 in. of final size and shape. From this point the processing varied depending on the surface that was to be produced. The purpose of the following methods of surface preparation was to determine if the conditions of machining or treatment produced an effect on the resulting fatigue life characteristics. It seemed reasonable to anticipate that they would, since the surface layers subject to the maximum stress during testing would be in different states of strain hardening and of residual stress depending upon how the specimens had been prepared.

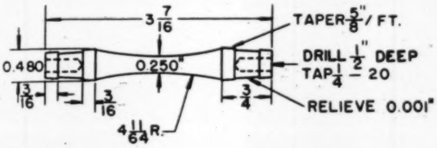

FIG. 1.—Fatigue Test Specimen.

The surface designated as hand finished, HF, was prepared by machining the specimens to within 0.005 in. of the final dimensions, annealing for ½ hr in argon at 1450 F, then hand finishing with metallographic papers through No. 000 grit to the final dimensions. The surface designated as rough machined-hand finished, RM, HF, was prepared by annealing the 0.050-in. oversize specimens in argon ½ hr at 1450 F, then machining to within 0.005 in. of final size, then hand finishing to the final size with metallographic papers. A third surface, rough machined, RM, was prepared by annealing the 0.050-in. oversize bars in argon at 1450 F for ½ hr, then finishing directly to size with a contoured tool to give the same surface finish as determined by a profilometer.

A shot peened surface, SP, was prepared by peening HF specimens to an Almen number of 10 using 0.010-in. steel shot in a Wheelabrator unit. An electropolished surface, E, was produced by removing 0.005 in. from the HF specimens electrolytically in an acetic acid-perchloric acid bath. Ground surfaces, G, were produced by preparing rough machined specimens to 0.025 in. oversize, annealing them, then grinding these specimens circumferentially using a Simonds WA46K5VI wheel with a surface speed of 4000 ft per min for rough grinding and 8840 ft per min for finish grinding.

Oxidized, O, and nitrided, N, surfaces of Ti-75A and RC-130B were also prepared. Specimens with an HF surface were prepared and exposed to purified oxygen and nitrogen atmospheres at 1450 F. For Ti-75A the oxidized surface was produced by a 12-hr exposure while the RC-130B was exposed for 2 hr, then annealed in argon for 4 hr to permit diffusion into the surface to occur. Nitriding was carried out by exposures of 16 hr for each alloy.

The fatigue properties of Ti-75A specimens prepared as described above were determined. The HF, RM, SP, G, HF-O, and HF-N surfaces of RC-130B were investigated. The HF, SP, and G surfaces were investigated on RC-A-110AT, the 6 per cent aluminum alloy, and the 30 per cent molybdenum alloy.

All the specimens receiving a given surface treatment were prepared as a group with extreme emphasis placed on maintaining uniform conditions of preparation. The same personnel performed each step in the processing and the test specimens are believed to be as uniform as it is possible to make them without going to unreasonable extremes.

Profilometer Measurements:

Subsequent testing indicated that surface finish was not of appreciable significance, but prior to this profilometer readings were made on several samples of each of the surface types. Table III lists these measurements made on the Ti-75A and RC-130B alloys.

TABLE III.—PROFILOMETER SURFACE CHARACTERISTICS.

Alloy	Heat	Surface Treatment[a]	RMS, microinches		
			Average	High	Low
Ti-75A	L-984....,	HF	10	12	8
		RM, HF	14	22	10
		RM	90	120	60
		SP	130	170	110
		E	7	10	3
		G	52	85	35
Ti-75A	M-270....,	HF-N	34	42	30
		HF-O	11	14	9
RC-130B	B-3562....,	HF	6	9	5
		RM	190	220	170
		SP	86	105	70
		G	40	60	25
RC-130B	B-3413....,	HF-N	22	40	13
		HF-O	13	16	8

[a] RM = Rough Machined, HF = Hand Finished, SP = Shot Peened, E = Electropolished, G = Ground, HF-O = Hand Finished and Oxidized, HF-N = Hand Finished and Nitrided.

Microhardness Measurements:

The usual microhardness measurements made across the surface and subsurfaces with a Tukon Tester using a 1000-g load revealed no hardness gradient, but by using a 25-or 50-g load a hardness contour could be detected. Because of the small impressions and the marked heterogeneity of the surface layers, there was a considerable scatter in any group of values at a given depth. To smooth these data a series of five impressions at a given depth were averaged. Figure 2 is a typical plot of the average diamond pyramid hardness of a ground Ti-75A surface. Two sets of readings are listed. One set is for readings taken perpendicular to the bar axis, while the other set is for readings taken parallel to the bar axis. The differences between the two sets of readings is traceable to the preferred orientations in the bar stock.

The depth of penetration of the finishing operation beneath the surface can be estimated from graphs of the type of Fig. 2. Table IV summarizes such data for the various surface treatments on Ti-75A and RC-130B.

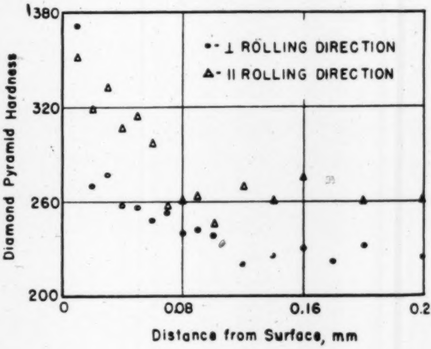

FIG. 2.—Microhardness Traverse from Surface of Ground Ti-75A Fatigue Test Specimen.

X-ray Studies:

X-ray analyses showed the presence of preferred orientation in the test materials. Since all the specimens were annealed in the same manner and could only be machined from the bars in one fashion, the effect of this preferred orientation can be considered to be a constant but one that probably can affect the fatigue properties. There is no way of changing the preferred orientation without introducing other extraneous effects such as grain growth.

TABLE IV.—ESTIMATED DEPTH OF SUBSURFACE ALTERATION FROM MICROHARDNESS STUDIES.

Material	Surface[a]	Estimated Depth, mm	Maximum Hardness, DPH		Center Hardness, DPH	
			⊥RD	∥ RD	⊥RD	∥ RD
Ti-75A	HF	0.12	260	340	220	262
	RM	0.20	360	318	245	265
	SP	0.25	445	355	255	230
	G	0.12	370	355	255	230
	E	0.0	230	260	220	250
	HF-O	0.05	450	290	250	265
	HF-N	0.06	340	345	210	212
RC-130B	HF	0.04	490	415	385	410
	RM	0.12	400	430	370	365
	SP	0.05	760	440	350	375
	G	0.08	415	455	365	400
	HF-O	0.20	470	600	415	440
	HF-N	0.19	545	580	400	375

[a] RM = Rough Machined, HF = Hand Finished, SP = Shot Peened, G = Ground, E = Electropolished, HF-O = Hand Finished and Oxidized, HF-N = Hand Finished and Nitrided.

The depth to which the various finishing operations penetrated beneath the surface was estimated by utilizing a forward reflection X-ray diffraction technique. Filtered copper radiation was allowed to strike the specimen surface at a glancing angle, and the diffracted beams were photographically recorded and then analyzed for the resolution of the $\alpha_1\alpha_2$ doublets. In a cold-worked or stressed condition this doublet is merged into a single line, but these doublets resolve as the stress is relieved by electrolytically removing the surface layers from the test specimens. The exact point at which sharpening occurs cannot be determined accurately, and this technique was only applicable to the Ti-75A, which showed the least degree of preferred orientation. Table V summarizes these measurements on the Ti-75A specimens.

TABLE V.—DEPTH OF SURFACE WORK MEASUREMENTS OF Ti-75A.

Surface Treatment[a]	Depth Below Surface, mils		Estimated[b] Depth of Work, mils
	Individual Spots Appear	Spots Sharp	
HF	4	6.5	<6.5
RM, HF	8	12.0	10.0
E	0	0	0
SP	9	20.0	12.0
G	3	>5.0	>5.0

[a] RM = Rough Machined, HF = Hand Finished, G = Ground, E = Electropolished, SP = Shot Peened.

[b] Estimated depth is somewhat less than the point at which spots are completely sharp.

Precision back-reflection X-ray diffraction measurements could not be used as a quantitative measure of the magnitude and sense of the residual stresses for several reasons. The shape of the test specimen, the lack of suitable radiation, preferred orientation effects, and variable interstitial element content all militated against the precise determination of the stresses. By utilizing a front-reflection technique, however on flat replica surfaces of the same type as that used on the fatigue specimens, the data of Table VI were obtained.

TABLE VI.—RESIDUAL STRESSES IN REPLICA SURFACES.

Material and Surface Finish[a]		Sense of Stress			Depth, mils
		Transverse	Longitudinal	Magnitude	
Ti-75A	HF	Compression	Compression	Slight	6–8
	RM, HF	Tension	Compression	Slight	6–8
	RM	Tension	Compression	Moderate	8–10
	G	Tension	Tension	High	9–11
	SP	Compression	Compression	High	12–16
RC-130B	HF	Compression	Tension	Slight	5–8
	SP	Compression	Compression	High	...
	G	Tension	Tension	High	...

[a] RM = Rough Machined, HF = Hand Finished, G = Ground, E = Electropolished, SP = Shot Peened.

TABLE VII.—SUMMARY OF FATIGUE TESTS.

Material	Test Surface[a]	Number of Specimens	Number of Stress Levels	Material	Test Surface[a]	Number of Specimens	Number of Stress Levels
Ti-75A L-984	HF	27	5	RC-130B B-3562	HF	30	5
	RM, HF	29	5		RM	29	6
	RM	25	5		G	31	6
	G	25	4		SP	26	5
	SP	24	4	B-3134	HF	18	3
	E	25	5	B-3413	HF	18	3
					HF-O	20	4
M-270	HF (1800 rpm)	24	4		HF-N	18	3
	HF (10,000 rpm)	36	6				
	HF (Water	11	3	RC-A-110AT	HF	13	5
	HF (Vacuum)	11	4		SP	15	5
	HF (H_2)	14	5		G	15	5
F[b]	HF	5	5				
R[b]	HF	8	8	All alpha	HF	16	6
					SP	16	6
					G	15	5
				All beta	HF	11	5
					SP	11	5
					G	11	5

[a] RM = Rough Machined, HF = Hand Finished, G = Ground, E = Electropolished, SP = Shot Peened.

[b] These were random lengths of random heats of unknown analysis and were run for comparison purposes. Data are plotted in Fig. 6.

Fatigue Testing:

Identical tests made at each stress level on the various R. R. Moore machines showed that there was no significant difference between the performance of the five units.

The internal heating that occurred in testing Ti-75A led to the investigation of the effect of speed of testing on the fatigue life of this material. The Ti-75A specimens were run at 1800 rpm, except where noted otherwise, while the balance of the specimens were run at 6000 rpm.

EXPERIMENTAL RESULTS

In order to treat the data statistically, six identical tests were planned at each stress level on each type of surface for the Ti-75A and RC-130B alloys. After this portion of the program was completed, the number of tests at each stress level for each surface on the remaining alloys was decreased to two or three specimens because of the limited quantity of these alloys that was available. Table VII lists the number of test specimens and stress levels investigated in obtaining the data being reported.

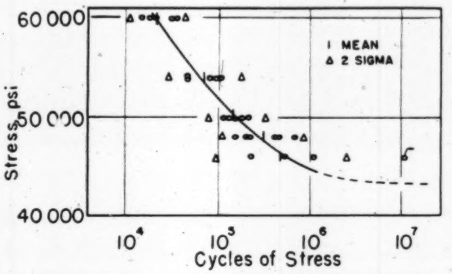

FIG. 3.—Fatigue Data Ti-75A, Hand Finished Surface.

Figures 3 and 4 are typical *S-N* curves obtained in the replicate testing of Ti-75A and RC-130B, each with a given type of surface. These are fairly representative of the data obtained on the various surfaces. The data at the higher stress levels appear to be more closely grouped about the mean than at the lower levels. In determining the mean value of a group of tests at a given stress, a log-normal distribution of the cycles to failure was assumed in view of other findings on the statistical nature of fatigue (3). A rigorous test of this normality could not be obtained from the data of this program, but by grouping the data, particularly the data on Ti-75A, indications were that the universe had an approximately log-normal form. The standard deviation from the mean is that of the universe and is computed from the sample deviation by the methods outlined in the usual statistics texts (7).

Figures 5 to 12 summarize the data of this research and show curves of best fit through the mean values as determined from the data presented in curves similar to those shown in Figs. 3 and 4. As such, these curves represent the best approximation to the *S-N* curve which would result from testing a universe of samples rather than a sample of thirty or less which has been tested. While the curves represent the mean fatigue life, the curve as it approaches 10^7 cycles of stress is an estimate of the endurance limit of the alloy. This property was not statistically determined and the values shown are the best estimates from available data. Data near the endurance limit are difficult to handle statistically. In a given group of specimens, some run out while others fracture, thus giving a mixed universe. In cases of this type the mean was based on the samples that fractured and the run-outs disregarded. The endurance limits on these curves are drawn just below the stress at which all the specimens of a given group run out. In practically all cases it is the stress at 10^7 cycles of stress.

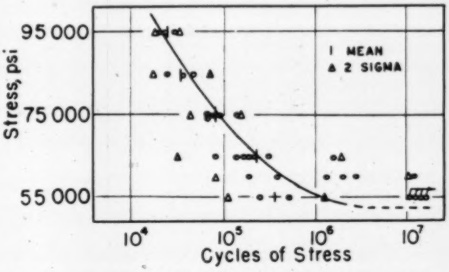

FIG. 4.—Fatigue Data RC-130B, Ground Surface.

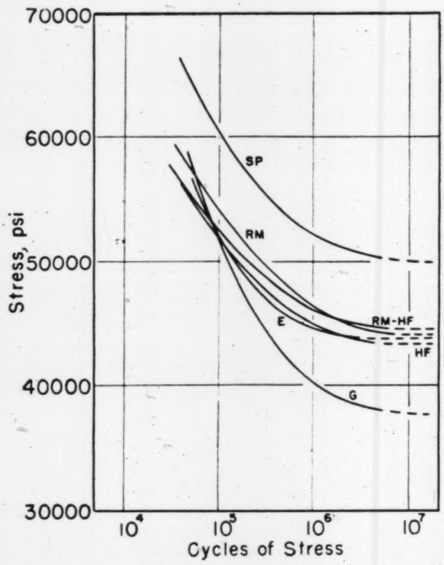

FIG. 5.—Summary Graph of Fatigue Data for Ti-75A, Heat L-984.

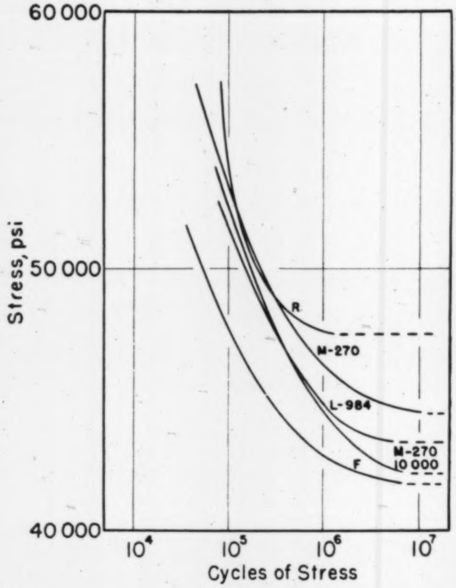

FIG. 6.—Summary Graph for Hand Finished Surfaces of Ti-75A.

DISCUSSION

In this investigation the surface designated as HF was taken as a standard surface. The data for the specimens from different heats of Ti-75A and RC-130B prepared in this fashion are given in Figs. 6 and 9. Since it was noted that the Ti-75A specimens became heated during testing, the speed of testing was varied and the curve labeled 10,000 in Figs. 6 and 7 is for data taken at this testing speed. In order to obtain some measure of the heating effect noted in these alloys, thermocouples were inserted into specially drilled test specimens and the temperature rise noted during testing. Table VIII lists some of the values obtained for several samples of Ti-75A with different surfaces and under different stresses. In general, the higher the test stress the greater was the temperature rise. The temperature rise in RC-130B is only a matter of 10 F and is due to the conduction of bearing heat

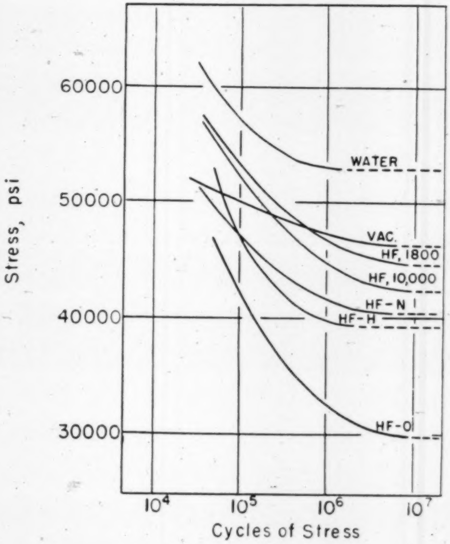

FIG. 7.—Summary Graph of Fatigue Data of Ti-75A, Heat M-270.

in the testing units. While the temperatures listed give a measure of the heating effect, they are not the true temperature of the test specimen since it was noted that at the point of failure the specimen becomes sufficiently hot to produce an oxide film on the test specimen, thus indicating a localized temperature of at least 800 to 900 F. Failure of these specimens is generally not a true fatigue type of failure. The specimen becomes so hot that it plastically deforms and terminates the test or else a hot-tearing type of failure occurs. In view of this intense internal heating, it was reasoned that making the tests under quasi-isothermal conditions would improve the fatigue properties. Water cooling of the specimens was tried during testing with the results shown in Fig. 7, which indicate that cooling does improve the fatigue life. The tests at 10,000 rpm indicate a somewhat poorer set of fatigue properties, probably because of the inability of the specimens to dissipate the heat that is generated.

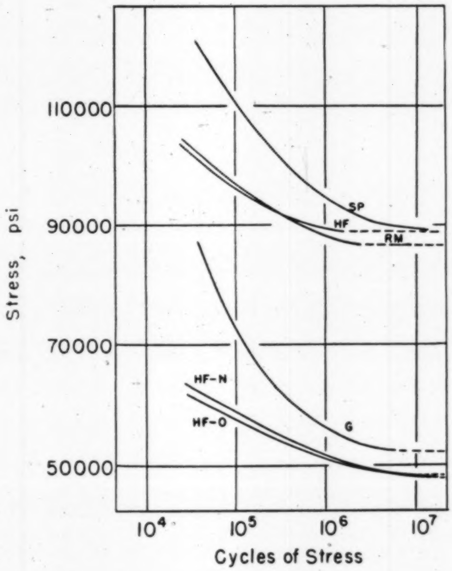

Fig. 8.—Summary Graph of Fatigue Data for RC-130B, Heat B-3562.

Part of the heat generated might well be due to the fact that the specimens of Ti-75A are being tested at stresses above their proportional limit and the heat liberated is due to the mechanical working. This same condition occurred, however, in testing the 6 per cent aluminum alloy, and here no measurable temperature rise was detected. For this reason, another source for the internal friction was sought. Since titanium reversibly takes up hydrogen into solution and since the Ti-75A had appreciable quantities present, as shown by the

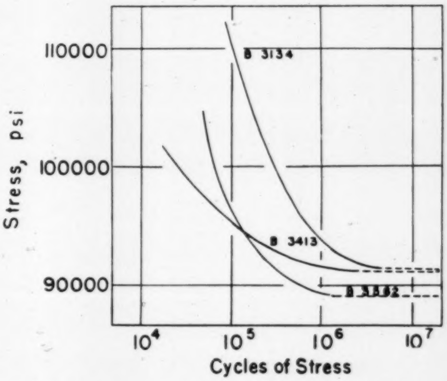

Fig. 9.—Summary Graph for Hand Finished Surfaces of RC-130B.

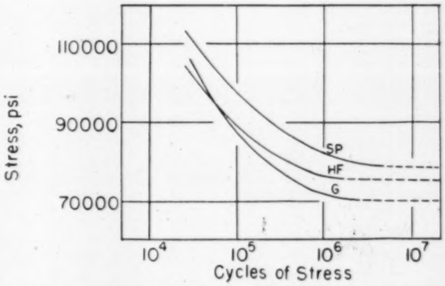

Fig. 10.—Summary Graph of Fatigue Data, 6 per cent Aluminum Alloy.

presence of line markings in the microstructures, this element was believed to be responsible for the friction. In order to test this theory, one portion of a group of specimens was heated in vacuo for 2 hr at 1600 F to decrease the hydrogen content, while the balance of the group was heated in 97 per cent argon-3 per cent hydrogen at the same temperature and for the same time period. The effect of these treatments on the fatigue properties is shown in Fig. 7, which indicates that the removal of hydrogen improves the fatigue properties. What is of more significance, however, is that the heating effect was not present in the vacuum-treated specimens, and the failure of these specimens was of the true fatigue type rather than the plastic oxidized type obtained with the as-received or hydrogen-treated specimens.

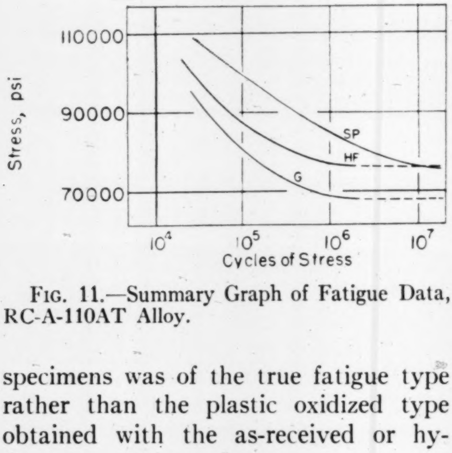

FIG. 11.—Summary Graph of Fatigue Data, RC-A-110AT Alloy.

The effect of nitriding or oxidizing the surfaces of Ti-75A is shown in Fig. 7. The presence of the hard brittle surface layers on these specimens is the probable cause of the poorer fatigue properties in that these layers could not adjust to the influence of the alternating stresses.

Figure 5 summarizes the effect of the various other surface treatments used on the fatigue properties of Ti-75A. It is apparent that the shot peening and grinding markedly alter the fatigue properties. There are differences between the specimens treated in other fashions but they are not marked. The effect of the shot peening is believed to be due to the cold working and retention of residual compressive stresses in the surface layers. This effect was shown metallographically, by the microhardness survey and by the X-ray analysis. The effect of grinding is also probably traceable to the residual tensile surface stresses in combination with a notched type of surface on a micro scale. While the ground surface showed a good profile on the profilometer, at high magnifications small notches were apparent metallographically where whole grains had been ripped from the surface during the grinding. The combination of these notches with the residual tensile stresses are believed to be the cause of the poorer fatigue properties. The grinding conditions used in this work were not particularly severe; the surfaces were smooth and clean with no indication of burning having occurred. More severe conditions would probably have still further reduced the fatigue properties, but it is doubtful that less severe conditions would have caused much improvement.

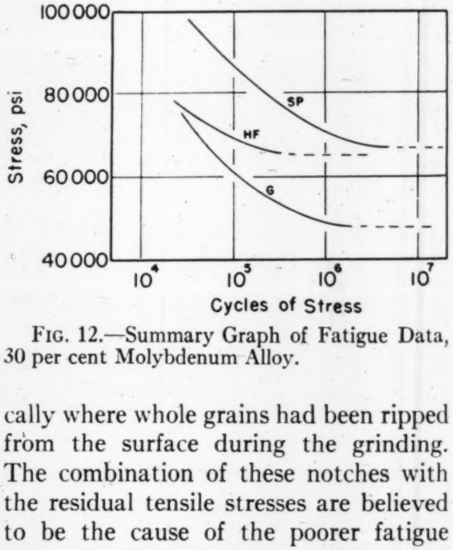

FIG. 12.—Summary Graph of Fatigue Data, 30 per cent Molybdenum Alloy.

It will be noted that there is no correlation between the surface finish of these alloys and their resulting properties.

TABLE VIII.—TEMPERATURE RISE IN FATIGUE SPECIMENS DURING TESTING AT 1800 RPM.

Alloy	Surface Treatment	Test Stress, psi	Temperature Rise, deg Fahr
Ti-75A	Shot peened	56 000	100
	Shot peened	52 000	100
	Rough machined	60 000	340
	Rough machined	54 000	100
	Rough machined	46 000	60
	Electropolished	48 000	70
RC-130B	Hand finished	110 000	10
	Shot peened	110 000	10

TABLE IX.—FATIGUE STRENGTH AS PERCENTAGE OF THE PROPORTIONAL LIMIT OR TENSILE STRENGTH OF THE ALLOYS.

Alloy	Surface Treatment	10^5 Cycles		10^7 Cycles	
		Proportional Limit, per cent	Tensile Strength, per cent	Proportional Limit, per cent	Tensile Strength, per cent
Ti-75A	HF	89.1	56.5	78.3	49.6
	HF	101.8	56.9	89.6	50.1
	HF	114.7	57.0	96.3	47.9
	RM, HF	116.1	57.8	99.0	49.2
	RM	120.0	59.6	97.8	48.6
	G	114.0	56.6	83.9	41.6
	SP	134.0	66.6	111.1	55.3
	E	114.8	57.1	97.3	48.4
	HF (Vac)	104.2	55.1	96.9	51.2
	HF (H_2)	97.6	51.6	82.4	43.5
	HF-O	87.7	46.4	62.2	32.9
	HF-N	98.2	52.0	84.6	44.8
RC-130B	HF	80.3	74.9	66.1	61.6
	HF	77.2	61.1	71.3	56.4
	HF	78.0	58.4	74.4	55.7
	RM	77.6	61.4	69.5	55.0
	G	58.2	46.1	42.1	33.0
	SP	89.1	70.5	71.4	56.5
	HF-O	47.6	35.6	39.4	29.5
	HF-N	46.5	34.8	39.7	29.7
RC-A-110AT	HF	70.4	63.2	61.5	55.3
	SP	84.7	76.1	61.7	54.9
	G	64.6	58.1	54.7	49.1
All Alpha	HF	108.0	67.5	92.1	57.1
	G	106.0	66.4	86.2	53.6
	SP	118.0	74.0	96.0	59.7
All Beta	HF	62.0	55.3	59.0	52.6
	G	55.6	49.6	43.4	38.7
	SP	78.5	70.0	60.2	53.7

Evidently other conditions have voided the usual dependency of the fatigue properties on the surface finish.

The data on the standard surface (HF) of the RC-130B alloys used are shown in Fig. 9, while the shot-peened, rough-machined, and ground data are shown in Fig. 8. In this material, a two phase alloy, the influence of shot peening in improving the fatigue life is only apparent in the short fatigue life region, and near the endurance limit these specimens are all comparable with the fatigue properties of the hand-finished or rough-machined surfaces. The effect of grinding is to produce noticeably inferior fatigue properties, while the effect of oxidizing and nitriding is to produce a marked decrease in fatigue life.

Figure 11 summarizes the data on the RC-A-110AT alloy. The shot peening improves the fatigue life only at the shorter cycles to failure region, while grinding decreases the fatigue life uniformly over that of the hand-finished material. Similar results, shown in Fig. 10 and 12, were obtained on the experimental all-alpha and all-beta alloys.

The data of Table IX present the stress for a stated fatigue life as a percentage of the proportional limit and tensile strength of the various alloys. It is apparent that there is a stronger correlation between the tensile strength and the strength for a given fatigue life than between the proportional limit and this same strength. For example, the stress for a fatigue life of 10^7 cycles of stress for Ti-75A for surfaces which have been hand finished, rough machined, electropolished, or vacuum treated appears to vary from 47.9 per cent to 50.1 per cent of the tensile strength. The presence of interstitial elements or grinding produces stresses that are smaller percentages of the tensile strength, while shot peening produces surfaces that show a greater percentage. In the case of the alloys, the hand-finished surfaces show higher percentages and vary from 52.6 per cent to 61.6 per cent and the shot peening is not effective in improving the fatigue life in these longer cycles of stress region. Grinding, as was the case in Ti-75A, produces a lower percentage of the tensile strength, although the 6 per cent aluminum alloy did not show so marked a decrease for this type of surface.

CONCLUSIONS

Except for shot peening and grinding, the influence of the method of surface preparation on the fatigue properties of Ti-75A and RC-130B is not marked.

Shot peening the surface of all alloys tested improves the fatigue life properties, particularly in the higher stress regions of the *S-N* curve. Its effect near the endurance limit appears significant only on Ti-75A.

Grinding the surfaces definitely decreases the fatigue life characteristics of all the alloys, particularly in the longer fatigue life region of the *S-N* curve.

Surface roughness does not appear to be of major significance in affecting the fatigue life characteristics in that its effect is masked in this study by other variables.

Heat to heat comparisons where they can be made indicate that variations from this source are not marked. In Ti-75A, the endurance limit is affected more than the fatigue life, while in RC-130B the reverse is true in that the fatigue life is affected more than the endurance limit.

The internal heating encountered in testing Ti-75A is believed to be due principally to the presence of dissolved hydrogen.

The standard deviation in cycles to failure at a given stress for a given surface condition is of the same order of magnitude as reported for other metals.

Acknowledgment:

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DISCUSSION

MR. L. P. TARASOV[1].—The authors' study shows that the fatigue properties of their ground specimens were in most cases much inferior to those obtained for similar specimens finished by other methods. However, there is ample reason for attributing the observed detrimental effect to improper grinding practice rather than to grinding in general.

The grinding conditions that were used by the authors would be satisfactory for steel specimens but are now known to be totally unsuitable for titanium. In precision grinding, aluminum oxide wheels are likely to smear and burn titanium when run at conventional speeds such as 6000 surface ft per min, and the same can happen even at 4000 surface ft per min, the speed used by the authors for rough grinding. Visual evidence of burning and smearing can disappear if the last pass of the wheel across the work is a very light one, but the damage will remain.

To obtain a satisfactory surface condition in titanium with aluminum oxide wheels, experience indicates that they should be run at extremely low wheel speeds, generally in the range of 1500 to 2000 surface ft per min, and that a suitable chemically active grinding fluid, such as a 5 per cent sodium nitrite solution, should be used. When this is done, the possibility of a chemical interaction between titanium and abrasive, which can occur at the high temperature existing momentarily at the point of contact, is greatly decreased, and this in turn results in the elimination of smearing and burning. If practical considerations require the use of conventional wheel speeds, then silicon carbide wheels should be used, again in conjunction with a suitable grinding fluid. The results may not be as good as when aluminum oxide wheels are used properly, but they will be better than when the latter are used dry at conventional speeds.

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[1] Norton Co., Worcester, Mass.

Although the authors claim that their grinding conditions were not particularly severe, they show that the surface was affected in several ways, at least one of which would certainly be expected to lower the fatigue properties. This refers to the notches observed at high magnification "where whole grains had been ripped from the surface in grinding." It is a widespread mistake to judge grinding severity by the externally imposed conditions, such as feeds and speeds; the important thing is the extent to which the ground surface is affected. A light cut may in some circumstances be more damaging than a heavy cut, and it simply confuses the issue to say that the latter corresponds to greater grinding severity. Thus the fact that part of the surface was ripped out in grinding, with the resultant notch formation, serves to refute the claim that grinding was not particularly severe.

The writer surface ground some small pieces of Ti-75A to see how the surface condition was affected by wheel speed and grinding fluid. At 6000 surface ft per min, the surface was badly smeared and burned when ground dry, and it was smeared about the same when ground with sodium nitrite solution, but it was not burned nearly as much. Smearing was always accompanied by torn-out areas with very ragged edges, the same condition that was found by the authors. There was no sign whatever of smearing or burning when the same solution was used, but with the wheel speed reduced to 1900 surface ft per min; under these grinding conditions, a good ground finish was obtained, without any torn-out areas.

The authors state that the surfaces of their ground specimens were smooth and clean, with no sign of burn. Smoothness is a characteristic of some smeared surfaces, which may give very low Profilometer readings because the grinding scratches have been smoothed over. That portions of the surface were torn out in these specimens is definite proof that the observed smoothness was caused by smearing, which the writer would expect anyway on the basis of the grinding conditions. The absence of burn is not significant since it could easily have been ground off with the following portion of the wheel as soon as it formed, or else during the final light pass of the wheel across the work.

The hardening of the surface to a considerable depth, particularly in Ti-75A, was another effect that was noted by the authors. This too must be attributed to the grinding procedure used because this effect is not found when titanium is ground properly. In fact, the writer was unable to find evidence of any hardness increase in the dry-ground piece of Ti-75A referred to above. An electropolished cross-section through the ground surface was prepared by Mr. Sinnott by the same technique as has been used for preparing the specimens on which the microhardness curves of Fig. 2 are based, in order to eliminate sample preparation as a possible source of any discrepancy. The writer then measured the diamond pyramid hardness on a Tukon Tester with 100-g load and found that the average hardness based on five indentations was in the range of 170 to 190, and that there was no sign of any hardness gradient to a depth of 0.15 mm (0.006 in.). Thus from the standpoint of work hardening, the writer's specimen was far less severely ground than the fatigue test specimens. This rather unexpected difference could be due to the big difference between the two grinding setups. This shows clearly that smearing is not necessarily accompanied by measurable work hardening, even in commercially pure titanium.

The main reason for dwelling in such detail on a single phase of this valuable paper is that grinding may be involved in the production of many titanium parts for military purposes, and it would be most unfortunate if it were erroneously concluded that titanium cannot be ground without serious damage fatiguewise. This paper does show how dangerous one *conventional* grinding practice can be in this respect for titanium, but it does not establish that grinding is necessarily detrimental. It will be highly desirable for those concerned with expanding the use of titanium to support further studies of the effects of *good* grinding practices on the fatigue properties of titanium; otherwise, the military uses of titanium may become unnecessarily restricted for fear of fatigue failures in parts requiring grinding.

MR. E. H. SCHUETTE.[2]—While the mean and 2-σ-limit curves at low stress levels were not actually used for final comparisons, I think in the interests of the best handling of data it is worth pointing out a lack of rigor that exists in arriving at these curves. When some of the specimens fail at a given stress level while others run out, it seems to me improper to make the statistical analysis on the basis of the failures alone. This arbitrarily eliminates the best bars from the population, for which there is no good justification. Our experience has shown us that these bars, if run long enough, would also fail eventually, and thus should be included in the analysis.

Several methods are available. One is to leave all bars at such stress levels out of the analysis, and arrive at the most reasonable curve on the basis of the rest of the data. Another is to use probability paper to find the most reasonable mean and 2-σ values for the truncated population that is available for study. Still another would be to analyze on the basis of the lives thus far realized, and then put arrows on the points for the mean and limits, showing in what direction they would be altered by the realization of greater lives for the run-out points. Any of these methods, I believe, would be better than the arbitrary "chopping-off" of a part of the population.

On the basis of a quick visual inspection, I am inclined to question the significance of the difference shown between results for 1800 cpm and 10,000 cpm testing.

MR. CARL E. HARTBOWER.[3]—One of the heats of Ti-75A used in this investigation was also used in an investigation at Watertown Arsenal. The chemical analysis for Ti-75A heat M-27O follows:

0.08 per cent C
0.106 per cent O
0.019 per cent H
0.060 per cent N
0.12 per cent Fe

Wide variations in interstitial content have been observed between heats of "unalloyed" titanium, even from a single commercial source. The variations are found to have a marked effect on notch sensitivity as measured by V-notch Charpy impact. It is suggested, therefore, that in all future researches involving titanium, complete chemical analyses should be obtained to establish individual differences between heats under investigation.

MR. T. J. DOLAN[4] (*by letter*).—It is unfortunate that the authors planned their experimental program to obtain data primarily at high stress levels. Most of the data, such as that shown in Figs. 3 and 4, are valid only for short fatigue life and do not give appropriate information about the *fatigue limit* of the material under the various conditions of surface finish. Only *estimates* of the fatigue limits are available, and it is difficult to extrapolate S–N curves with any assurance of accuracy. For this reason, some of the statements such as "shot peening improves the fatigue life only at the shorter cycles to failure region" need to be reconsidered. Data at the University of Illinois[5] have indicated that shot peening gives a marked improvement in fatigue limit of titanium alloys when tests are conducted to at least 20,000,000 cycles of stress in sufficient quantity to determine the endurance limit statistically.

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It does not seem entirely rational to obtain the average life of a group of fatigue specimens by disregarding those which run-out without failure, as was done by the authors. For example, at the stress of 55,000 psi in Fig. 4, six specimens were tested; four were disregarded and the mean life computed from the two which broke. This has the effect of giving an abnormally low life for the group and could result in considerable error when obtaining an estimated endurance limit by extrapolating the curve. Thus the data listed in Table IX for 10^7 cycles may be considerably in error.

MR. J. D. MARBLE (*by letter*).[6]—The authors are to be congratulated on this work and in particular the statistical analysis and metallurgical analyses. There is one phase of the work that would have greatly aided the analyses made. This is a more complete determination of the exact endurance limit of each of the groups of specimens. In some of the curves very few of the specimens tested were run at a stress where no failure occurred. It is evident from the indefinite regions shown on the summary graphs, that the authors also feel that these regions were incompletely investigated. With a very few additional specimens these regions could be determined accurately and then perhaps the other work on attempting to find correlation between some conditions of the surface layer and the fatigue properties of materials might be much more fruitful. If any more specimens or even any more of the materials from which these specimens were made still exist, it is hoped that the authors would be able to complete this phase. The excellence of the remainder of the work makes this small additional effort seem imperative so that the other phases of the work will not have to be repeated by some later investigator.

The effect of nitriding of the surface should be publicized not only by stressing it in the "Conclusions" on this work, but also by the various suppliers of titanium alloys. This is necessary because the effect is detrimental and is contrary to the effect on fatigue strength normally produced by this process. Therefore, its use should be prevented until further investigation can show that a modification of the process is no longer harmful or sufficient evidence is gained to show that the process will always be detrimental.

We agree with Mr. Tarasov's comments that the grinding methods used were perhaps not the correct ones for this type of material. However, even those methods which have been modified to make them as favorable as possible to the production of high fatigue properties in titanium alloys have still resulted in reductions in fatigue strength. This has been the conclusion of work done not only in our own company, but also in work done under contract for us by the University of Illinois. We would appreciate additional suggestions from Mr. Tarasov on methods of grinding which might be less detrimental.

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[5] G. M. Sinclair, H. T. Corten, and T. J. Dolan, "Effect of Surface Finish on the Fatigue Strength of Titanum Alloys RC103B and Ti140A," *Preprint 55-A-197*, Am. Soc. Mechanical Engrs., November, 1955.

[6] Metallurgical Sub-Section, Materials Laboratory, Development Department, Cincinnati, Ohio.

We are ourselves engaged in work attempting to find a correlation between machining methods and fatigue strength. Therefore, we would appreciate greatly the use of some of the RC-130B and RC-A-110AT specimens for study along these lines.

MESSRS. A. W. DEMMLER, JR., M. J. SINNOTT, AND L. THOMASSEN (*authors' closure*).—We agree wholeheartedly with Mr. Tarasov's remarks regarding the use of the term "severity" as generally applied to grinding. It was our intention to convey the idea that the procedure used was not "severe" in the conventional, though inaccurate, sense of the term. Our precise grinding procedure was given so that there would be a basis upon which to judge its severity. The procedure used was the best suggestion available for grinding at the time the work was begun in mid-1952 and was continued throughout in order to eliminate variations from this source.

It should be brought out that, while the microstructures immediately beneath the surface were altered somewhat by the grinding procedures, they did not appear to be smeared in the usual sense of the word. Much more evidence of plastic displacement of the material was evident from the other means of surface preparation such as shot-peening and machining.

It is possible that part of the absence of a detectable hardness gradient was due to the 100-g load used. As mentioned, we could not detect it with a 1000-g load but could with 50-g or, preferably, 25-g load. Thus, it is difficult to say what might be expected using 100 g.

It is hoped that the information presented here will not serve to give the grinding of titanium a generally bad name but rather to point out that it is important to search for the best grinding procedure for a given application in order to avoid this marked decrease in fatigue strength.

Regarding Mr. Schuette's remarks on the statistical handling of the data, it must be agreed that by using the method of our paper we are throwing some data away. This is regrettable, but by handling it in this way we have hoped to err on the safe side from the point of view of design. Rigorously, the sole solution appears to be that of sampling by attributes rather than by variables. By this method the only problem would be to determine an arbitrary number of cycles, such as 10^7, which would be considered to be the dividing line between those failing and "running out." This is feasible at the endurance limit but hardly so at higher levels of stress and in any case would require a notably larger number of specimens, which at the time of this presentation would have been prohibitive in cost.

Leaving out all of the specimens at a stress level having a mixed universe of values would discard much valuable data, as frequently there would be only one run-out in six specimens. It seems that there is little that probability paper can do that ordinary statistics cannot. We are more inclined to use Mr. Schuette's last suggestion of analyzing on the basis of realized lives and showing the means and limits with arrows showing possible longer lives. It is still felt, however, that it is better, for engineering purposes, to err on the weak side than to falsely overestimate mean physical properties.

Regarding the significance of the

difference between the curves at different testing rates, reference should be made to Fig. 5. It will be noted that four of the curves representing different surfaces cluster together in the central portion of the group. Due to the heating taking place at high stress levels, the uppermost stress level was neglected as was the lowest at which there were some runouts. The results of analyses of variance with one or three criteria of classification showed there to be differences between these four surfaces, statistically, though for engineering purposes these are so small as to be negligible. The variances can be shown to be homogeneous. Publications originating at Carnegie Institute of Technology and elsewhere have also shown differences in uncooled fatigue strengths at different rates of testing in Ti-75A or RC-55.

We should like to thank Mr. Hartbower for his more complete analysis of Ti-75A heat M-270. It is appreciated that analyses such as these for interstitial alloying elements may throw much light upon certain variations in physical properties—especially impact and certain high-temperature properties. Judging from our Fig. 6, however, they would not have served too much purpose in this particular investigation and thus were not made.

Mr. Dolan's comments on the investigation of fatigue limit are quite to the point. It was the purpose of this study, however, to investigate the fatigue curves in the region of 10^4 to 10^7 cycles to failure. With the same number of specimens to be used in determining the fatigue limit by either staircase testing or probit analysis, a far more precise evaluation could have been made.

Since so many curves of the type shown in Figs. 3 and 4 were available upon which to base estimates, it is felt that the errors in Table IX are not very large (though the third figure is undoubtedly not significant in an engineering sense). It may be seen from Fig. 4 that the curves used for making these estimates are more likely to fit the general trend of the data points than are the calculated means which admittedly must leave out some of the data.

We are unable to comply with Mr. Marble's suggestion of extending the work due to the fact that each heat was entirely used up as the work progressed. As for the effect of nitriding, it is necessary to point out that only one type or method of nitriding was used here, and since it necessitated different thermal treatment from that given most of the other specimens, further studies should be made before an all-inclusive conclusion may be reached.

TORSION PRESTRAIN AND THE FATIGUE STRENGTH OF RC-55 TITANIUM ALLOY*

By J. G. Kaufman[1] and E. D'Appolonia[2]

Synopsis

The effect of torsional prestrain on the behavior of RC-55 titanium alloy has been studied with rotating-beam fatigue tests.

Torsional prestrain ranged from 5 to 60 per cent of the torsional strain to failure. Rotating-beam specimens were machined from the twisted alloy and tested at 10,000 rpm and room temperature (70 F). Data from tests of torsionally prestrained specimens were compared with data from tests of otherwise similar specimens that had not been prestrained.

The effect of stress concentrations on RC-55 titanium alloy prestrained in torsion was also studied. Notched fatigue specimens were made of virgin bars and of bars that had been prestrained in torsion. These specimens were tested in a rotating-beam machine at 10,000 rpm and room temperature.

Internal heating was studied by comparing data from tests of unnotched specimens at room temperature with data from tests conducted while water circulated over the specimen. Tests with coolant were made on one high and one low range of prestrain.

The tests listed above were duplicated on two groups of specimens which had been prestrained in tension to approximately 20 and 40 per cent, respectively, of the true strain to fracture. Notched and unnotched specimens—with and without liquid coolant—were tested for each prestrain.

Repeated attempts to resolve the phenomena of failure by repeated loading have resulted in the discovery of numerous factors which in their own way affect the behavior of materials subjected to repeated loading. Efforts toward this end have been directed at the mechanism propagating failure within the material, at external conditions affecting the behavior of materials, and at the effects of history of loading on the behavior of materials. This study of torsional prestrain falls into the third category.

Torsional prestrain is a type of history of loading directed at the source of fatigue failure—the outer surface. It is postulated (**1**)[3] that the minute flaws and impurities on the surface of a specimen or machine part are the starting points of the propagating cracks. This is particularly so with rotating-beam tests where the outer fibers are carrying the maximum stress. Any improvement in the outer fibers of a material would benefit its rotating-beam fatigue behavior.

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* Presented at the Fifty-eighth Annual Meeting of the Society. June 26–July 1, 1955.

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[3] The boldface number in parentheses refer to the list of references appended to this paper, see p. 1012.

Previous research (**2**) has shown that tensile prestraining, which is uniform over a cross-section, improves the fatigue behavior of titanium. One might expect an even greater improvement if the prestraining is torsional. In that case, the maximum prestraining occurs at the outermost fibers where the stress is a maximum in rotating-beam tests. With torsional prestrains, the fibers of a circular cross-section are prestrained in proportion to their distance from the center; even for large prestrains, only the outermost fibers are plastically deformed.

TESTING PROGRAM

The problem of accurately straining specimens of a size that could be tested in R. R. Moore fatigue machines was solved by the construction of a miniature torsion machine. A program of testing was set up to examine the effects of torsional and tensile prestraining on the fatigue properties of notched and unnotched titanium alloy specimens. The tensile prestrain was included to provide a comparison for the torsional prestrain. Coolant tests also were conducted on two ranges of both tensile and torsional prestrain for the purpose of eliminating the effect of internal heating. It has been shown (**3**) that internal heating has a destructive effect on the fatigue life of titanium, particularly at a testing speed of 10,000 rpm, and that this effect can be removed by using a water coolant. (Therefore, a spray of water maintained at 70 F was played on the rotating specimens at all times.) This elimination of the damaging effect of internal heating permitted a truer evaluation of the effect of prestraining on the fatigue behavior of titanium.

Some basis was needed for comparing the results of the torsional and tensile prestrains. The concept of effective strain (**4**) was used for this comparison. Derived from distortional energy, effective strain is defined by:

$$\epsilon_E = \frac{\sqrt{2}}{3}\sqrt{(\epsilon_x - \epsilon_y)^2 + (\epsilon_y - \epsilon_z)^2 + (\epsilon_z - \epsilon_x)^2 + \tfrac{3}{2}(\gamma_{xy}{}^2 + \gamma_{yz}{}^2 + \gamma_{zx}{}^2)}$$

TABLE I.—STATIC MECHANICAL PROPERTIES OF RC-55 TITANIUM ALLOY.

Property	Value
Rockwell Hardness, C scale	15–17
Modulus of elasticity, psi	$15\text{–}16 \times 10^6$
Yield stress at 0.2 per cent offset, psi	61 000
True tensile strength, psi	118 000
Nominal tensile strength, psi	78 000
True ultimate strain at fracture, in. per in.	0.73
Elongation in 2 in., per cent	39.0
Reduction of area, per cent	52
Torsion strain at fracture (diameter = 0.375 in.), in. per in.	1.3
Torque at fracture (gage = 8 in., diameter = 0.375 in.), ft-lb	74.5
Torque at proportional limit (gage = 5.5 in., diameter = 0.375 in.), ft-lb	40.0
Twist at proportional limit (gage length = 5.5 in., diameter = 0.375 in.), radians per in	0.1

where ϵ_x, ϵ_y, ϵ_z, γ_{xy}, γ_{yz}, and γ_{zx} are the normal and shear strains. In the case of pure tension with large plastic strains and Poisson's ratio assumed as one half,

$$\epsilon_x = \epsilon_y = -\frac{\epsilon_z}{2}$$

so that the effective strain reduces to:

$$\epsilon_E = \epsilon_z$$

which is the longitudinal strain measured. In pure torsion, all normal strains and γ_{xy} are zero, so that:

$$\epsilon_E = \frac{\sqrt{3}}{3}\sqrt{\gamma_{xz}{}^2 + \gamma_{yz}{}^2} = \frac{\sqrt{3}}{3}\gamma_r$$

with the shear strain, γ_r, being measured at right angles to the axis of twist.

If effective strain is assumed to be

independent of the type of loading, it provides a simple means of correlating fatigue results for torsional and tensile prestrained specimens. (If effective strain is used for the fracture strains in tension and torsion, the values are 0.73 in. per in. and 0.75 in. per in., respectively, where 0.73 in. per in. is the true tensile fracture strain.)

Comparisons are made with previous data (**2**) which deal with tensile prestrains.

Static mechanical test data on the RC-55 titanium alloy are given for purposes of correlation.

MATERIAL USED

The material used was RC-55 titanium alloy, heat Nos. RIA-110, 112, and 113. The chemical analysis for this alloy showed 0.160 per cent carbon, 0.050 per cent nitrogen, a few hundredths of 1 per cent oxygen and iron, other elements a trace, and titanium 99 per cent plus. The three heats are similar in physical and mechanical properties and were used together throughout the testing. Random samples from the three heats were selected for all tests.

The material was received in $\frac{5}{8}$-in. diameter bars and cut into 27-in. lengths. Hardness readings taken on all bars indicated that Rockwell hardness varied from C15 to C17. All tests were conducted on the material as received. Tension and torsion tests were made to determine the static mechanical properties. Test data are summarized in Table I.

SPECIMENS

Fatigue tests were conducted with specimens for R. R. Moore rotating-beam machines. The specimens were 3 in. long with a minimum diameter of 0.225 in. The diameter at the root of notched specimens was also 0.225 in.

The specimens used for torsion prestrain consisted of a small cylinder with a diameter of 0.35 in. at the center and gripping surfaces at the ends. The ends of the specimens had a cylindrical portion for axiality plus flats for gripping.

Tension prestraining extended into the plastic range where necking occurred. For this reason a slight curvature was given to the tension specimens to localize necking at the mid-section of the specimens. Both the torsion and tension prestrain specimens were large enough to allow R. R. Moore rotating-beam specimens to be machined from them once prestraining was completed.

All specimens were machined on a Logan 10-in. lathe at 400 rpm and polished by holding oiled 400A Tufbak Durite paper against the rotating specimen.

APPARATUS

A lathe stock formed the basis of the torsion machine used to prestrain specimens. Head and tail stock chucks were added to grip the small prestrain specimens. The head chuck is an integral part of the head stock shaft, and the tail chuck is held rigidly by the tail stock. The chucks themselves consist of a cylindrical slide (for axiality) slotted to grip specimens.

The angle of twist was measured by means of a dial and needle pointer mounted on the ends of the gage length.

Tension prestraining was done on a Tinius Olsen tension machine. Micrometers were used to measure instantaneous diameters.

Coolant tests were performed by using a small pump to circulate the water at room temperature over the rotating specimens.

PROCEDURE

For purposes of control and comparison, fatigue tests were run on RC-55 titanium alloy specimens without prestrain or notches.

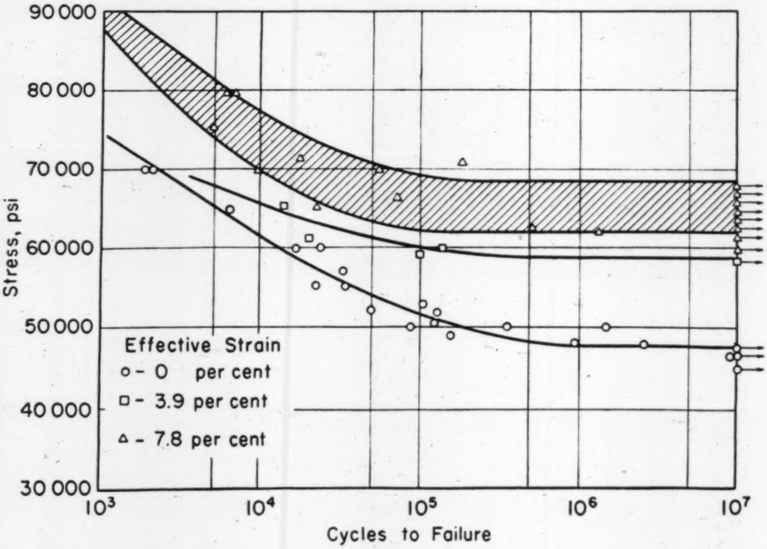

FIG. 1.—*S-N* Diagrams for RC-55 Titanium Alloy Prestrained in Torsion to 0, 3.9, and 7.8 per cent Effective Strain and Tested at 10,000 rpm Without Coolant.

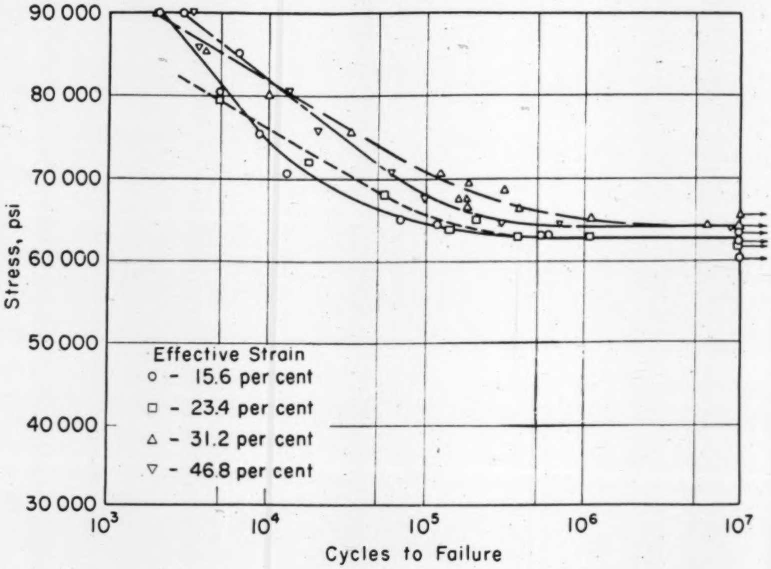

FIG. 2.—*S-N* Diagrams for RC-55 Titanium Alloy Prestrained in Torsion to 15.6, 23.4, 31.2, and 46.8 per cent Effective Strain and Tested at 10,000 rpm Without Coolant.

TABLE II.—ENDURANCE LIMITS FOR RC-55 TITANIUM ALLOY PRESTRAINED IN TORSION AND TESTED AT 10,000 RPM WITHOUT COOLANT.

Effective Torsional Prestrain, per cent	Endurance Limit, psi
0	47 500
3.9	58 000–60 000
7.8	62 000–68 000
15.6	62 500
23.4	62 500
31.2	63 500
46.8	63 500

Six levels of torsional prestrain were applied to the torsion specimens. These levels were 5, 10, 20, 30, 40, and 60 per cent of the total strain to failure, corresponding to 3.9, 7.8, 15.6, 23.4, 31.2, and 46.8 per cent effective strains. (Henceforth, all strains referred to will be effective strains.) All strains are for the final diameter of 0.225 in., assuming that the shear strain varies linearly with distance from the center. Following straining, the specimens were machined into R. R. Moore rotating-beam specimens and tested at 10,000 rpm without coolant and with coolant maintained at 70 F.

Two levels of tensile prestrain were applied to the tension specimens—15 and 30 per cent effective strain—to compare with similar values of effective torsional prestrain. The tensile strains are based on true strain defined as twice the logarithm of the original diameter over the instantaneous diameter.

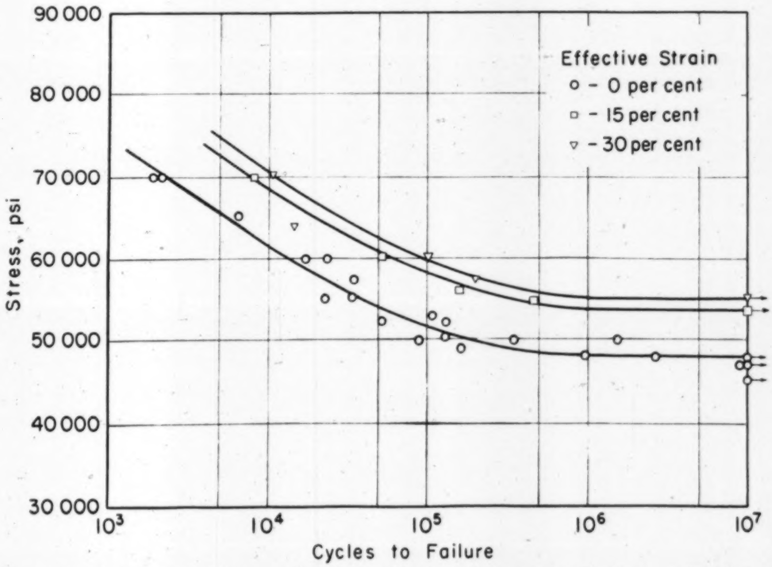

FIG. 3.—*S-N* Diagrams for RC-55 Titanium Alloy Prestrained in Tension to 0, 15, and 30 per cent Effective Strain and Tested at 10,000 rpm Without Coolant.

Notch tests were made on tension and torsion prestrained specimens at 10,000 rpm without coolant. Effective prestrains of 15 and 30 per cent were used for this series of tests on specimens whose theoretical stress concentrations were 1.78 and 3.48. Stress concentrations were based on tables given by Neuber (**5**) and Peterson (**6**).

Coolant tests were made on specimens prestrained to two values of torsional and tensile prestrain to discover the effect of internal heating at 10,000 rpm. A clearer picture of the effect of tor-

TABLE III.—ENDURANCE LIMITS FOR RC-55 TITANIUM ALLOY PRESTRAINED IN TENSION AND TESTED AT 10,000 RPM WITHOUT COOLANT.

Effective Tensile Prestrain, per cent	Endurance Limit, psi
9	47 500
15	54 000
30	55 000

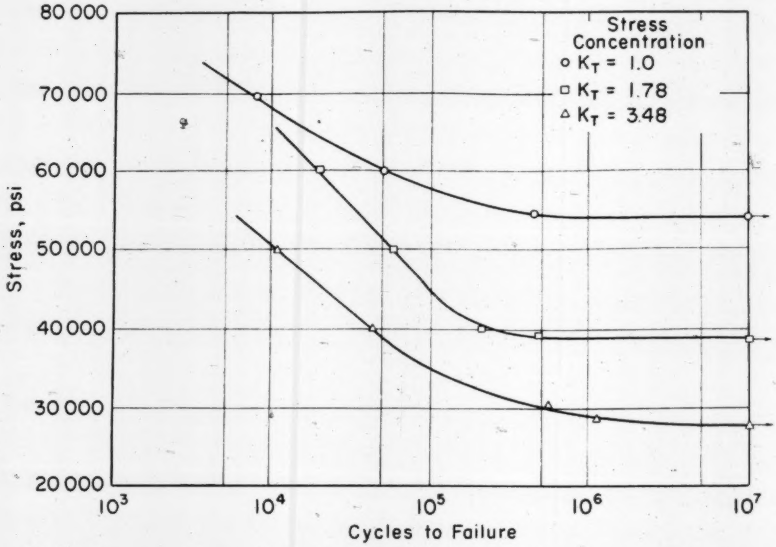

FIG. 4.—*S-N* Diagrams for Notched RC-55 Titanium Alloy Prestrained in Torsion to 15.6 per cent Effective Strain and Tested at 10,000 rpm Without Coolant.

sional and tensile prestrains would thus be obtained. Tests were made on torsion prestrained specimens with effective strains of 7.8 and 31.2 per cent and on tension prestrained specimens with effective strains of 15 and 30 per cent.

RESULTS

Control:

Figure 1 shows nominal stress and number of cycles for RC-55 titanium alloy without prestrain and without coolant. (Nominal stress for rotating-beam specimens is based on a linear theory.) It has been noted in fatigue tests that titanium shows a well-developed endurance limit at 3 × 10^6 cycles. Repeated testing to 5 × 10^7 cycles around the endurance limit resulted in no failures of specimens. This has been substantiated by previous work (**7, 8**). Henceforth, instead of speaking of the fatigue strength at 10^7 cycles, the term endurance limit will be used. The endurance limit without prestrain was 47,500 psi.

Torsional Prestrain:

Figures 1 and 2 show nominal stress and number of cycles (*S-N*) for the tests conducted at 10,000 rpm and without coolant on specimens with various degrees of torsional prestrain. Table II lists the endurance limits for these tests.

Tensile Prestrain:

The results of the fatigue tests on specimens prestrained in tension are shown in Fig. 3. Table III is a summary of the endurance limits and effective strains.

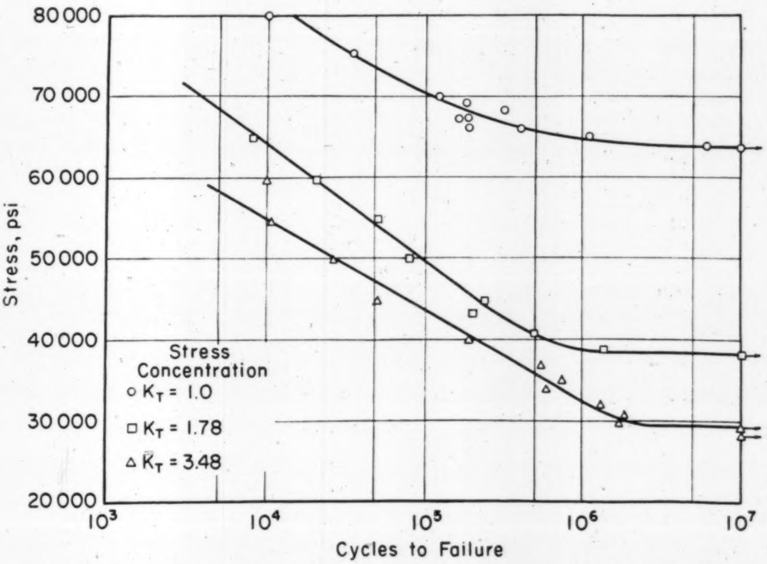

FIG. 5.—*S-N* Diagrams for Notched RC-55 Titanium Alloy Prestrained in Torsion to 31.2 per cent Effective Strain and Tested at 10,000 rpm Without Coolant.

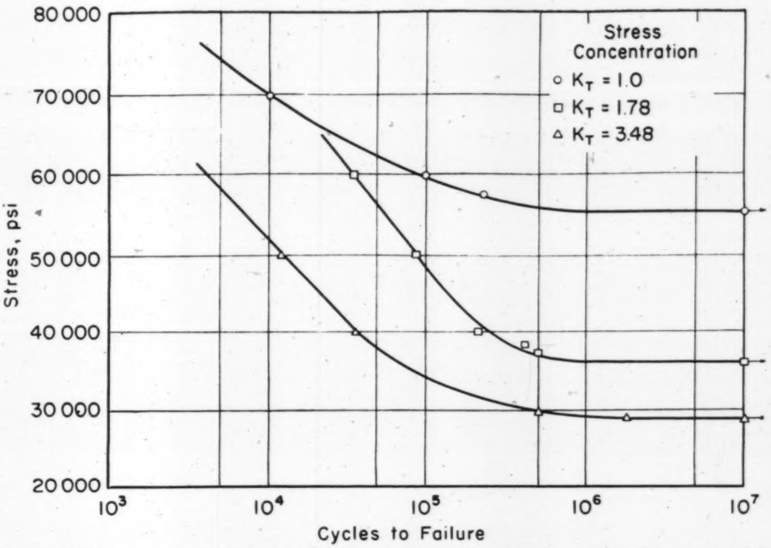

FIG. 6.—*S-N* Diagrams for Notched RC-55 Titanium Alloy Prestrained in Tension to 15 per cent Effective Strain and Tested at 10,000 rpm Without Coolant.

Notch Studies:

The *S-N* diagrams for torsional and tensile prestrains with stress concentrations of 1.78 and 3.48 are shown in Figs. 4 to 7. Specimens prestrained to 15 and 30 per cent effective strains in both torsion and tension were used. Table IV gives the endurance limits obtained in these tests.

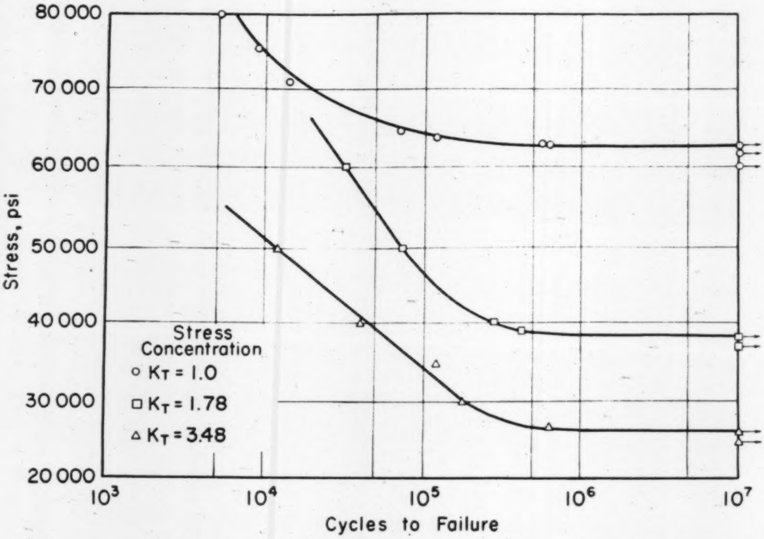

Fig. 7.—*S-N* Diagrams for Notched RC-55 Titanium Alloy Prestrained in Tension to 30 per cent Effective Strain and Tested at 10,000 rpm Without Coolant.

Coolant:

In Fig. 8 are shown the results of the coolant tests conducted on specimens prestrained in torsion and tension. Specimens prestrained to 7.8 and 31.2 per cent effective strain by twisting or 15 and 30 per cent effective strain by pulling were used. Table V summarizes the endurance limits for these tests.

TABLE IV.—ENDURANCE LIMITS FOR NOTCHED RC-55 TITANIUM ALLOY PRESTRAINED IN TORSION AND TENSION AND TESTED AT 10,000 RPM WITHOUT COOLANT.

Type of Prestrain	Effective Strain, per cent	Stress, Concentration, K_T	Endurance Limit, psi
None	0	1.78	43 000
Torsion	15.6	1.78	38 000
Torsion	31.2	1.78	38 000
Tension	15.0	1.78	38 500
Tension	30.0	1.78	36 000
None	0	3.48	32 000
Torsion	15.6	3.48	26 000
Torsion	31.2	3.48	29 000
Tension	15.0	3.48	27 000
Tension	30.0	3.48	28 000

PREVIOUS WORK

For comparison the results of previous work on the effect of tensile prestrain on the endurance limit of RC-55 titanium alloy (1) are tabulated in Table VI. These tests were conducted at 1800 rpm on a heat of RC-55 with slightly different carbon and nitrogen contents from those of heat Nos. RIA-110, 112, and 113 used in this investigation.

Previous studies of the effect of notch geometry on the fatigue behavior of RC-55 were used to determine the en-

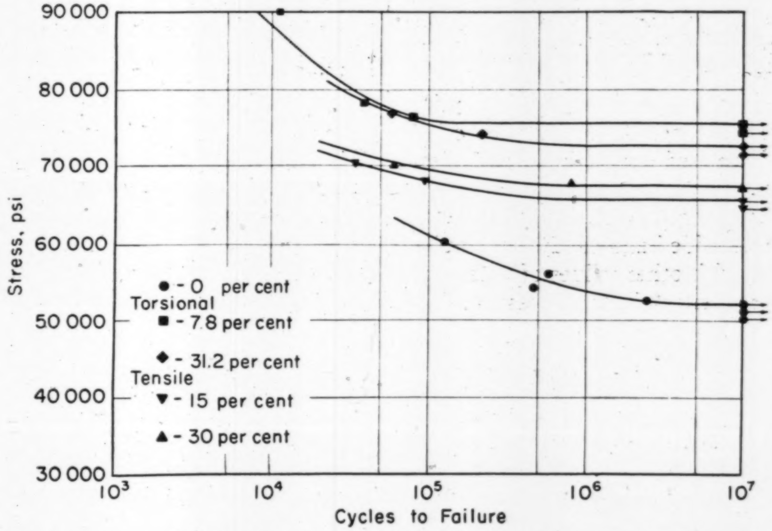

FIG. 8.—*S-N* Diagrams for RC-55 Titanium Alloy Prestrained in Torsion to 0, 7.8, 31.2, and in Tension to 15 and 30 per cent Effective Strain and Tested at 10,000 rpm with Coolant Maintained at 70 F.

durance limit of notched specimens without prestrain. Fatigue strength reduction factors were used as obtained from tests at 10,000-rpm. These values as determined from the previous data are included in Table IV.

DISCUSSION OF RESULTS

Torsional Prestrain:

Figure 9 shows that prestraining in torsion significantly improves the fatigue life of unnotched RC-55 titanium alloy, with the most marked increases in endurance limit occurring in the range from 0 to 10 per cent effective torsional prestrain. At 10 per cent prestrain, the increase in endurance limit is about 30 per cent of the endurance limit of specimens not prestrained (47,500 to 62,500 psi). Torsional prestrains greater than 10 per cent effective strain produce small additional increases in the endurance limit above 62,500 psi. It should be noted, however, that despite the high percentage of prestrain, no destructive

TABLE V.—ENDURANCE LIMITS FOR RC-55 TITANIUM ALLOY PRESTRAINED IN TORSION AND TENSION AND TESTED AT 10,000 RPM WITH COOLANT MAINTAINED AT 70 F.

Type of Prestrain	Effective Strain, per cent	Endurance Limit, psi
0	0	52 500
Torsion	7.8	75 000
Torsion	31.2	73 000
Tension	15	66 000
Tension	30	67 000

TABLE VI.—ENDURANCE LIMITS FOR UNNOTCHED RC-55 TITANIUM ALLOY PRESTRAINED IN TENSION AND TESTED AT 1800 RPM WITHOUT COOLANT.[a]

Effective Tensile Prestrain, per cent	Endurance Limit, psi	Percentage Increase in Endurance Limit
0.0	46 000	...
0.4	49 000	6.5
4.0	50 000	8.7
10.0	51 000	10.8

[a] Data taken from reference (**9**).

effects were evident near the endurance limit or in the finite-life range. This is clearly seen in Figs. 1 and 2. The tests of specimens with the largest prestrains (31.2 and 46.8 per cent) show finite life ranges improved over those with less prestrain.

At 7.8 per cent effective strain (Fig. 1), there was a wide band of fatigue failures compared with other values of prestrain. Some specimens failed at stresses as low as 63,000 psi, whereas others reached 2 or 3 × 10^7 cycles without failure at all stress levels up to 68,000 psi. This wide variation was observed only at the 7.8 per cent effective prestrain. It would appear that, at this value of effective prestrain, the specimens are on the verge of undergoing large plastic deformation. Since the plastic deformation does not occur uniformly at all fibers on the circumference and along the specimen, the scatter found at 7.8 per cent effective strain is to be expected. The stress in rotating-beam specimens is a maximum in a region of anisotropic yielding (**10**). Some of the fibers are deformed elastically while others are deformed plastically by the prestraining. This anisotropy evidently is both damaging and beneficial in a random manner, a fact which probably accounts for the large variation in fractures at 7.8 per cent effective strain. It was noted, for example, that some specimens with 7.8 per cent effective prestrain became red hot (approximately 700 F) and were greatly distorted at failure whereas others broke cleanly. This is in contrast to other tests. Without prestrain, all specimens became red hot and failed with ragged distorted fractures. On the other hand, specimens with more than 15 per cent effective strain were free from severe heat effects and broke cleanly. Since at 7.8 per cent effective strain both behaviors were noted, there is further indication that this value is in

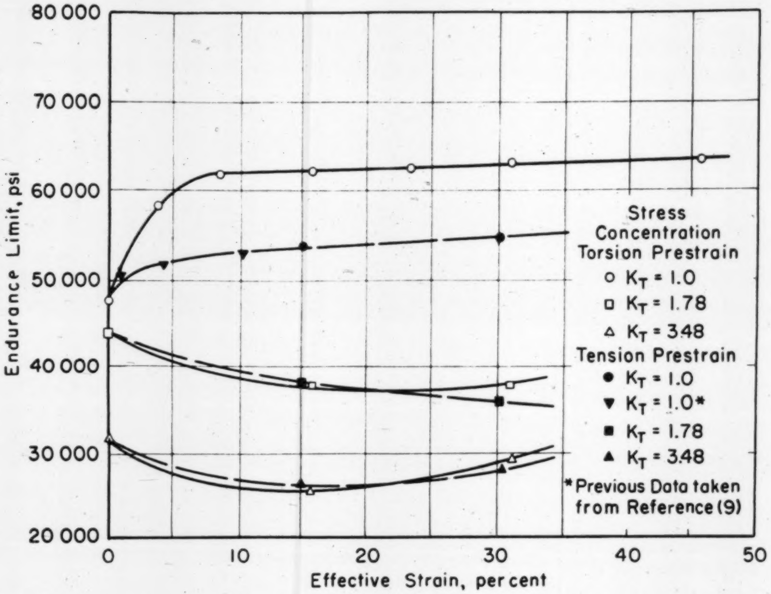

FIG. 9.—Endurance Limit - Effective Strain Relation for Notched and Unnotched RC-55 Titanium Alloy Prestrained in Tension and Torsion and Tested at 10,000 rpm Without Coolant.

the transition region between the two types of fatigue failure—heating with ragged fractures and no heating with clean fractures.

These effects were also noted to a lesser degree in the 3.9 per cent effective strain (Fig. 1). However, the complete curve was not determined and conclusions cannot be drawn.

Comparison of Torsional and Tensile Prestrains:

It is evident from Fig. 9 that prestraining in torsion provides a greater improvement in the fatigue behavior of titanium than does prestraining in tension. In all cases, the increase in endurance limit with torsional prestrain is at least twice that with tensile prestrain.

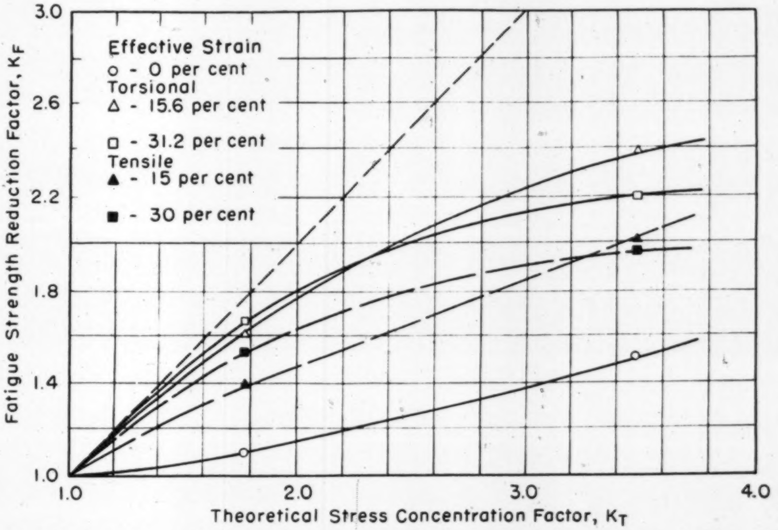

FIG. 10.—Fatigue Strength Reduction Factor and Theoretical Stress Concentration Factor for RC-55 Titanium Alloy Prestrained in Tension and Torsion and Tested at 10,000 rpm Without Coolant.

Tensile Prestrain:

Figure 9 indicates that there is a small increase in endurance limit as a result of tensile prestrain. RC-55 titanium alloy shows an increase of 16 per cent for the largest effective prestrain of 30 per cent.

A comparison of these data with the previous data (**9**) on tensile prestrain, included in Fig. 9, indicates a direct correlation. Despite the good correlation, it must be kept in mind that the previous work was done on a different heat of RC-55 alloy and at a testing speed of 1800 rpm.

Specimens with identical histories of loading in the outer fibers, as defined by effective strain, do not behave identically when tested in a rotating-beam machine. This may be attributed to one or more of the following factors: (1) the difference in the strain distribution throughout the specimen for the two types of prestrain, (2) difference in the crystalline structure of the specimens after torsional or tensile prestrain, or (3) anisotropy of the plastic deformations for torsional prestrains.

Notch Studies:

Figure 9 also shows the combined

results of the tests on unnotched specimens. Prestrain data were obtained from previous results (9) on RC-55 titanium alloy.

It is seen in Fig. 9 that for both tensile and torsional effective prestrain for both values of theoretical stress concentration the endurance limits for notched specimens were remarkably close. The maximum separation between tensile and torsional prestrains with notches is 3000 psi. This is a small difference considering the experimental errors involved in fatigue testing and prestraining.

For theoretical stress concentrations of 1.78 and 3.48, a 30 per cent effective tensile prestrain resulted in a slightly lower endurance limit than did a similar torsional prestrain. At 15 per cent effective strain, the reverse was true. These differences, as was pointed out before, are small and not too significant. For both tensile and torsional prestrained specimens with a stress concentration of 3.48, the endurance limit at 30 per cent effective strain was higher than it was at 15 per cent. Here again the difference was small and probably not significant. With prestrain, the endurance limit of notched specimens was always lower than it was without prestrain. Concentrating the stress at one point by means of the notch probably results in the more damaging effects of prestrain becoming apparent, a fact also indicated in previous work (9).

Theoretical stress concentration and the fatigue strength reduction factor are shown in Fig. 10. Because of the greater increase in endurance limit with torsional prestrain than with tensile prestrain and because of the similar values of endurance limits with notches, the fatigue strength reduction factor is much larger for the torsional prestrain than for the tensile prestrain.

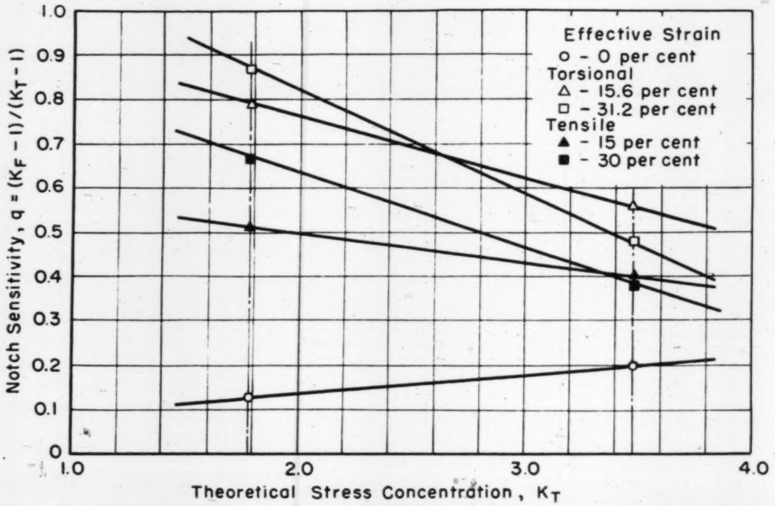

FIG. 11.—Notch Sensitivity and Theoretical Stress Concentration Factor for RC-55 Titanium Alloy Prestrained in Tension and Torsion and Tested at 10,000 rpm Without Coolant.

Figure 11 is a plot of notch sensitivity and theoretical stress concentration. Since only two points were available for each plot, they have been arbitrarily connected with straight lines. Two significant trends remain apparent. First, as prestrain increases, the slope of the notch sensitivity curves become increasingly negative. Without prestrain, notch sensitivity increases with stress concentration; with prestrain, notch sensitivity decreases with stress concentration in some proportion to prestrain. The second trend which completely offsets the other is the fact that the notch sensitivity of specimens with prestrain increased over that of specimens without prestrain.

It is thus clear that, although the prestrains studied are beneficial to specimens of unnotched titanium alloy, they are harmful to notched specimens.

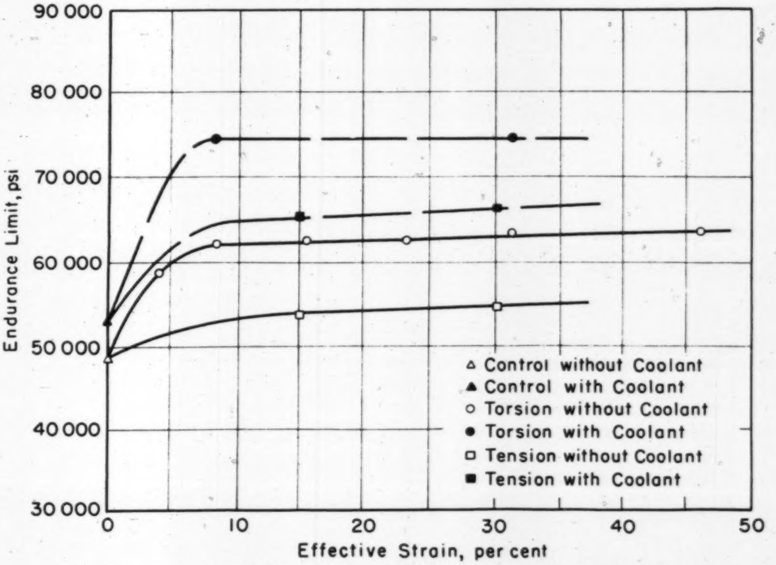

Fig. 12.—Endurance Limit - Effective Strain Relation for RC-55 Titanium Alloy Prestrained in Tension and Torsion and Tested at 10,000 rpm with and Without Coolant Maintained at 70 F.

Coolant—Tensile and Torsional Prestrain:

By spraying the specimen with water at 70 F, the endurance limit was greatly increased (Fig. 12). Specimens without prestrain had the smallest increase in endurance limit (47,500 to 52,500 psi); other increases were considerably larger.

The most striking effect of the coolant was that it not only increased the endurance limit of specimens that were prestrained to 7.8 per cent effective torsional strain but that it also reduced the width of the band of test results obtained without coolant. The endurance limit was 75,000 psi, an increase of 20 per cent over the endurance limit of specimens without coolant (62,000 psi). It was also a 43 per cent increase over the endurance limit (52,500) of specimens not prestrained and run with coolant.

At 31.2 per cent effective torsional prestrain, the endurance limit was 73,000 psi. Figure 12 shows that, for torsional prestrains greater than 10 per cent effective strain, the endurance limit is unaffected and remains practically constant.

Endurance limits of specimens prestrained in tension and tested with coolant increased about 12,000 psi at 15 and 30 per cent effective strain over specimens tested without coolant. This improvement in endurance limit was about 22 per cent.

As Fig. 12 indicates, coolant did not

minimize the difference between the endurance limits resulting from torsional and tensile prestrains. Torsional prestrains either with or without coolant produced greater increases in the endurance limit than did tensile prestrains.

CONCLUSIONS

The following conclusions may be drawn from this study of torsional prestrain and related subjects:

1. Torsional prestrain has a beneficial effect on the endurance limit of unnotched RC-55 titanium alloy specimens. The increase in endurance limit is most significant at effective prestrains up to 10 per cent.

2. Tensile prestrain, which also has a beneficial effect on the fatigue life of RC-55 titanium alloy, is not so beneficial as torsional prestrain.

3. Identical histories of loading (as defined by effective strain) for the outer fibers of a rotating-beam specimen do not produce identical variations in endurance limit.

4. For prestrained notched rotating-beam specimens:

   (*a*) The endurance limit is independent of the types of prestrain studied.

   (*b*) With notches, more damage is produced with prestrain than without prestrain.

   (*c*) The fatigue strength reduction factor is higher for torsional than for tensile prestrain.

5. Testing RC-55 titanium alloy with coolant raises the endurance limit of prestrained specimens but does not decrease the difference between the endurance limits of tensile and torsional prestrained specimens.

Acknowledgment:

The research was conducted under the auspices of Watertown Arsenal under Contract No. DA-36-061-ORD-362, Ordnance Research and Development Project No. TB4-15, Department of Army Project No. 599-08-021, and the project was under the technical supervision of the Applied Mechanics Branch of the Watertown Arsenal Laboratories.

The authors express their indebtedness to F. T. Mavis for his advice in this work.

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DISCUSSION

Mr. P. R. Toolin.[1]—In Figs. 10 and 11, the fatigue strength reduction factors and notch sensitivity values are based upon tests performed without coolant. Perhaps these values should be qualified by noting that the unnotched fatigue specimens showed appreciable temperature rise and that the metal at the base of the notch should run at a lower temperature than the unnotched specimens. (This is due to the cooling effect of the metal surrounding the relatively small amount of material at the notch root which is at high stress.) In cases such as this the actual metal temperatures are dependent upon the geometry of the specimen, type of loading, axial or bending, and the testing frequency. Thus the notch factors may not represent true room temperature values.

Mr. J. G. Kaufman (*author*).—That certainly would seem to be the case, and I must agree that the specimens without the notches and without the prestrains ran very warm and were very distorted at fracture, while the specimens with the notches were essentially of a very clean, brittle fracture type.

The only comment would be that it seems a little irregular to me to compare data obtained by two different testing methods; that is, if we were to test unnotched specimens with the water coolant and notched specimens without. I wonder if it would not be a little irregular to compare such data directly.

Mr. C. R. Smith.[2]—Data of this sort may lead to unconservative estimates of real fatigue life improvement if used for axial rather than bending stresses. The residual compressive stresses on the surface due to torsion prestrain would provide lower tensile stresses than calculated for test, so that the fatigue life improvement here is largely because of testing at a lower stress for the same load, rather than because of actual improvement in fatigue strength. Had these same specimens been tested axially, the fatigue life improvement would have been limited to the protection afforded by a compressive layer on the surface such as provided by shot peening.

Mr. Kaufman.—As Mr. Smith has noted, and I whole-heartedly agree, the results of this investigation apply only to rotating-beam fatigue and it was not the authors' intention that the results should be considered valid for axial fatigue tests also. I also am inclined to agree that the beneficial effect, if any, of torsion prestrain on the axial fatigue characteristics of RC-55 would be smaller than it was on the rotating-beam characteristics. In the case of axial stressing, the entire cross-section is under high stress, not just the portion of the specimen with the maximum benefits of torsional prestrain as is the case with rotating-beam fatigue.

Mr. B. J. Lazan.[3]—I should like to ask the authors if they have any indications of the actual temperatures on the uncooled or cooled specimens during the early part of the test. Also did the temperature rise during the test?

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[1] Mechanics Department, Westinghouse Research Lab., East Pittsburgh, Pa.

[2] Consolidated Vultee Aircraft Co., San Diego, Calif.

[3] Professor of Materials Engineering, Experimental Engineering Building, University of Minnesota, Minneapolis, Minn.

Damping tests on RC-55 indicate that damping increases very rapidly as one approaches fatigue strength, and also becomes very sensitive to the number of cycles at stress levels which cause fatigue failure. One should expect the specimen temperature to reflect the high and changing damping. Did the authors take any temperature reading during the fatigue tests?

MR. KAUFMAN.—No actual temperature measurements were made during my particular investigation. Mr. D'Appolonia and Mr. Romualdi[4] did do considerable work along these lines so far as measuring the changes in temperature as the fatigue test progressed. They found that the surface temperature of specimens remained constant in the early stages of repeated loading, then the temperature increased and specimens glowed red at fracture.

I would like to thank all the contributors for their discussion and interested response to the paper.

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[4] J. P. Romualdi and E. D'Appolonia, "The Effects of Internal Heating on the Fatigue Properties of Titanium," Office Chief of Ordnance, Research and Development Branch, WAL Report No. 401/68-28, Contract No. DA-36-061-ORD-259, July, 1953.

EFFECT OF AN ANODIC (HAE) COATING ON THE FATIGUE STRENGTH OF MAGNESIUM ALLOY SPECIMENS*

By J. A. Bennett[1]

Synopsis

The nonmetallic coating produced electrolytically on magnesium alloys by the HAE process provides greatly increased resistance to corrosion. In order to determine the effect of the coating on fatigue strength, bending fatigue tests of coated and uncoated specimens were made in machines of the constant-amplitude-of-deflection type. The results showed that the coating caused a significant reduction in fatigue strength even when the stress on the coated specimens was calculated on the assumption that all the load was supported by the underlying metal. The coating usually provided sufficient protection so that the fatigue strength was not reduced by salt spray exposure. There was no significant difference in the effect of the coating between smooth and notched specimens.

The HAE process, developed by the Pitman-Dunn Laboratories, Frankford Arsenal, produces electrolytically on magnesium alloys a nonmetallic coating that is hard and corrosion-resisting [2] The Metallurgy Division of the National Bureau of Standards was asked by Frankford Arsenal to evaluate the effect of the coating on the fatigue strength of the base metal. This paper summarizes the results of that evaluation.

All of the tests were made on a magnesium alloy of the 3 per cent aluminum, 1 per cent zinc, and 0.3 per cent manganese type (AZ31X). Comparison tests were made on bare specimens and specimens having one of three different coating thicknesses applied after machining. The two thicker coatings, B and C, Table I, were similar to those usually used for components, and only the results on these coatings are presented. The results for the thin coating are consistent but show a smaller effect. All of the specimens were prepared at Frankford Arsenal Five types of specimens (Fig. 1) were tested as cantilever beams in Krouse reversed bending fatigue testing machines. As noted in Table I, one set of specimens was tested in unidirectional bending, that is, the minimum stress was approximately zero. All the other tests were conducted with the mean stress approximately zero.

Results of tests on type No. 1 specimens are shown in Fig. 2. These are typical of the data from all the series of tests, in that the curves tend to converge at higher stresses. Some of this convergence may be due to the testing method, for the

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* Presented at the Fifty-eighth Annual Meeting of the Society, June 26–July 1, 1955.

[1] Chief, Mechanical Metallurgy, National Bureau of Standards, Washington, D. C.

[2] M. Frager and H. A. Evangelides, "Getting the Most from HAE Coatings," *Metal Progress*, Vol. 62, September, 1952, p. 81.

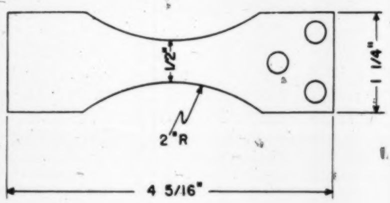
TABLE I.—SUMMARY OF FATIGUE STRENGTH VALUES.

Specimens			Remarks	Fatigue Strength at 10^7 Cycles (Stress Amplitude), psi			
Type	Thickness, in.	Test Section		Bare	Coated[a]	Coated, Corrected[b]	Net Reduction
No. 1	0.25	2-in. rad	Mean Stress = 0	13 200	C— 9 300	9 700	3 500
No. 2	0.25	¼-in. diam hole		10 000	C— 7 400	7 700	2 300
No. 3	0.094	¼-in. diam hole		12 700	C— 8 500	9 400	3 300
No. 4	0.094	4-in. rad		12 500	B—11 000	11 600	900
No. 5	0.04	4-in. rad		11 500	B— 9 500	10 700	800
No. 5	0.04	4-in. rad	Minimum Stress = 0	9 500	B— 6 700	7 600	1 900

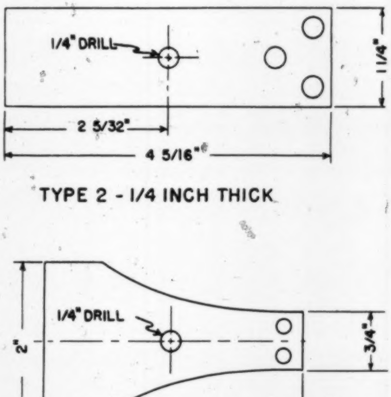
[a] The letters preceding the values in this column identify the coating applied.
[b] The fatigue strength of the base metal at 10^7 cycles assuming that the coating has no strength.

following reasons: in fatigue tests under constant amplitude of deflection, the cracks form at a relatively early stage of the test, and the crack growth stage occupies an appreciable portion of the total fatigue life. It has been shown for other materials[3] that the proportion of the fatigue life occupied by this stage increases with increasing stress amplitude. As the coating affects only the number of cycles required to start a crack, the effect of coating on the total fatigue life would decrease with increasing stress amplitude.

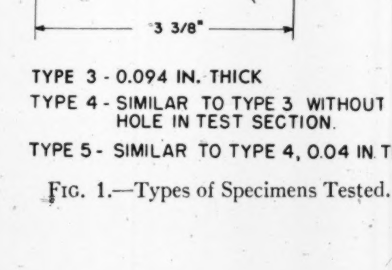
On the basis of the above considerations, the most reliable estimate of the effect of the coating should be obtained from tests at low stress levels where the number of cycles to initiate cracking is large in comparison with the crack growth portion of the test. As the *S-N* curves appeared to be nearly horizontal at 10^7 cycles, most of the tests were discontinued if the specimens ran this long without failure. The comparisons for the six series of tests in Table I are based on the stress at which 50 per cent of the specimens "ran out" to 10^7 cycles, determined as shown on the right of Fig. 1.



TYPE 1 - 1/4 INCH THICK



TYPE 2 - 1/4 INCH THICK



TYPE 3 - 0.094 IN. THICK
TYPE 4 - SIMILAR TO TYPE 3 WITHOUT HOLE IN TEST SECTION.
TYPE 5 - SIMILAR TO TYPE 4, 0.04 IN. THICK.

FIG. 1.—Types of Specimens Tested.

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[3] J. A. Bennett and J. L. Baker, "Effects of Prior Static and Dynamic Stresses on the Fatigue Strength of Aluminum Alloys," *Journal of Research*, Nat. Bureau Standards, Vol. 45, December, 1950, p. 449.

Because of its nature, the coating would not be expected to contribute appreciably to the strength of the specimen. The loads used in setting up the tests were calculated on the basis of the total thickness of metal plus coating, so that the actual stress on the underlying metal was higher than the nominal value. Measurements with a Filmeter (American Instrument Co.) indicated that the thickness of coating B was about 0.0015 in., and that of coating C about 0.0025 in. On the basis of these values, the stresses listed for coated specimens in Table I were recalculated using the thickness of the metal only, giving the "corrected" stress values.

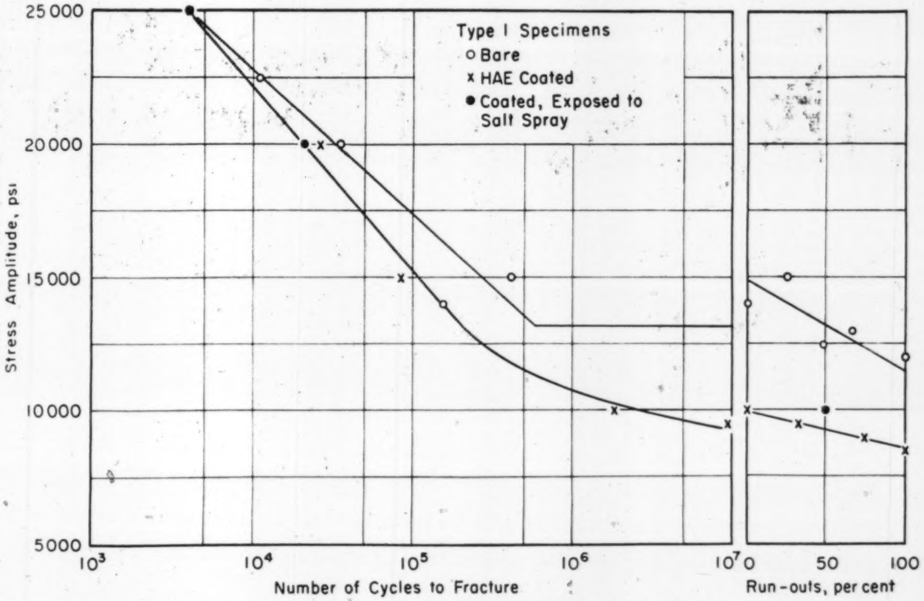


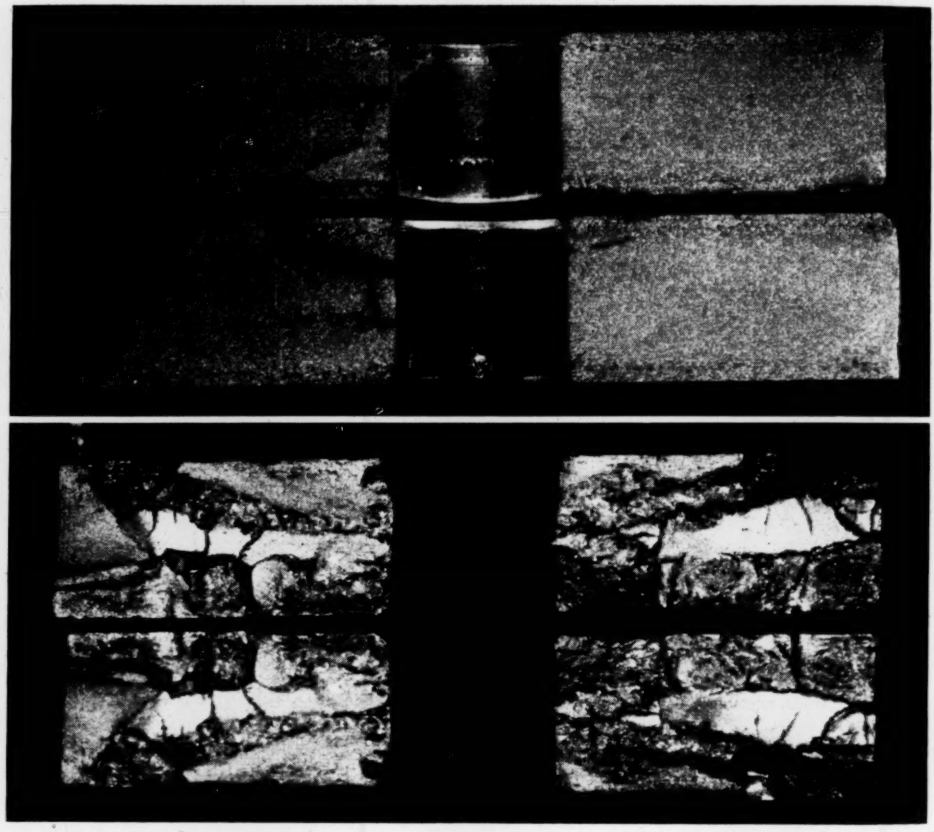
FIG. 2.—Results of Fatigue Tests of Type No. 1 Specimens.

The points in the left portion of the graph represent median values from at least three tests at the same stress level.

Direct microscopic measurement of the coating thickness on metallographic specimens gave average values about 25 per cent less than those from the Filmeter. The difference probably resulted from the Filmeter probe being supported on the high spots of the film. As the micrometer would be similarly supported in measuring the specimen thickness, it appeared that the Filmeter measurements were the logical ones to use for calculating the stress on the base metal.

The differences listed in the last column of Table I show that the coating actually reduced the fatigue strength of the underlying metal. This reduction was greater for greater coating thickness and amounted to approximately a 1000-psi decrease in fatigue strength for each 0.001 in. of coating. Such an effect might be produced by residual stress, and this explanation is consistent with the reduced effect at high stress levels—a residual stress would be eliminated by repeated stressing of sufficient magnitude to cause appreciable plastic deformation.

The effect of corrosion on the fatigue strength of the coated material was evaluated by tests of eight specimens (type No. 1, coating C) that had been exposed to salt spray (20 per cent NaCl (*a*) Bare, stress amplitude 11,000 psi Fractured in 233 × 10^3 cycles.



(*b*) HAE coated, stress amplitude 10,000 psi. Fractured in 624 × 10^3 cycles.

FIG. 3.—Surfaces of Fractures in Type No 2 Specimens (× 3½).

solution, 95 F) for five days. These specimens were tested at two stress levels, and the results are plotted as solid circles in Fig. 2. While the median values show no effect due to the exposure, one specimen, which had a large corrosion pit in the reduced section, failed in less than half the number of cycles survived by the rest of those tested at the same stress level.

There was a marked difference in the appearance of the fracture surfaces of the bare and coated specimens, as shown in Fig. 3. The rougher surface of the coated specimen is believed to indicate that the coating provides a larger number of equally effective nuclei for the initiation of fatigue cracks than there are under equivalent conditions on the bare specimens. A number of cracks joining to form the final fracture would result in a rough fracture like that shown for the coated specimen (Fig. 3).

The magnesium alloy showed very low notch sensitivity; the value of q (as defined in the ASTM Manual on Fatigue Testing)[4] was about 0.3 for both bare and coated specimens made from the $\frac{1}{4}$-in. thick material. The reduction of fatigue strength due to the coating was also nearly the same for both smooth and drilled specimens. This may indicate that the lower fatigue strength of the coated specimen was not due to cracking of the coating, as this would be expected to be more severe at points of strain concentration.

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[4] Manual on Fatigue Testing, Am. Soc. Testing Mats. (1949). (Issued as separate publication *ASTM STP No. 91*.)

CONCLUSIONS

The HAE coating reduced the fatigue strength of the alloy tested. Based on the stress for a life of 10^7 cycles, the reduction was somewhat greater than that calculated on the assumption that the coating had no strength.

The coating generally, but not invariably, provided sufficient protection so that the fatigue resistance of the specimens was not decreased by exposure to salt spray.

Acknowledgment:

The fatigue tests were conducted by Mr. H. Babb.

DISCUSSION

MR. E. H. SCHUETTE.[1] — Lest the results shown by Mr. Bennett be too discouraging, I would like to point out that such large reductions in fatigue strength are not characteristic of all anodic coatings. The Dow No. 17 coating, which gives the same general protection as the HAE coating, has been shown in tests to result in a decrease of only 3 to 5 per cent in fatigue strength. Such a decrease is quite inconsequential when compared with normal scatter and lot-to-lot variations in the metal.

MR. J. A. BENNETT (*author*). — I appreciate Mr. Schuette's comments. There is always a danger in presenting a paper of this kind because of the delay between the time of doing the work and the time of presenting the results. I know that this field of anodic coatings for magnesium alloys is very active and probably the specific data on this particular coating is obsolete, even now, but I think some of the other points in the paper may be of general interest. I hope that we will have the opportunity to hear a paper presenting Mr. Schuette's results at some subsequent ASTM meeting.

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[1] Chief, Design Section, Metallurgical Laboratory, The Dow Chemical Co., Midland, Mich.

STRENGTH OF BENT COPPER TUBE*[1]

By G. S. Sangdahl, Jr.,[2] and W. M. Baldwin, Jr.[2]

Synopsis

It has been the general belief that copper tubes are weakened by bending, due to a thinning of the wall thickness. This investigation was undertaken to determine whether such weakening does or does not take place. The results provide evidence that, in spite of this thinning of the wall, the bursting strength of the copper tube is not impaired by bending. Annealed copper tubes of diameters ranging from ⅝ to 1⅜ in. and in two wall thicknesses were tested. The bursting tests made on these tubes bent (by bend drawing) to radii of two, four, and six times the diameter have shown that the bursting strength of the bent tubes is greater than it is for unbent tubes. Additional tests made on ⅝- and ⅞-in. diameter tubes bent to radii less than two times the diameter still maintained higher bursting strengths than the unbent and unstrained tube, even though strains as high as 46 per cent were obtained for these bends. Strains as high as this are even larger than the necking strain for the copper tubes as determined from tension tests. An analysis of the strains involved in bending has also been made. An equation has been derived which fits the conditions of draw bending and gives the bending strains in terms of the bend radius.

Pipe lines and tube installations are playing an increasingly important part in our modern-day economy. With the increasing need for the transportation of fluids such as steam, water, hydraulic oil, compressed air, gases, fuel oil, refrigerants, lubricants, and a large variety of processed materials, the demand for such installations is now greater than ever before. Copper has become especially desirable as a tube material because of its resistance to many corrosive solutions, its excellent ductility, and its smooth interior which minimizes frictional losses. As is well known, a large portion of the production of copper tube goes into water pipe installations in private and commercial buildings and in industrial plants. In most of these installations, directional changes are made with the use of soldered fittings rather than by bends in the tube. Although this type of connection is more expensive and time-consuming than a simple bend in the tube, it supposedly results in a stronger unit. Many believe that bending weakens a tube and makes it unsafe for service, since there is a reduction of the wall thickness on the outer radius of the bend. This reduction of strength has been mentioned in at least two articles on this subject (**1**, **2**).[3]

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* Presented at the Fifty-eighth Annual Meeting of the Society, June 26–July 1, 1955.

[1] Conducted by Case Institute of Technology, in cooperation with Copper and Brass Research Assn.

[2] Research Assistant, and Research Professor, respectively, Case Institute of Technology, Cleveland, Ohio.

[3] The boldface numbers in parentheses refer to the list of references appended to this paper, see p. 1037.

It is not generally realized, however, that this thinning of the outer wall of a bent tube is accompanied by a strengthening of metal through cold work and that this strengthening is greater than the reduction of strength caused by the thinning of the material. This, perhaps, can best be shown by comparing the mechanical behavior of the metal on the tension side of the bend with the behavior of the metal in an ordinary tension test.

In the tension test two factors must be considered as the load is applied. One is the reduction of cross-sectional area, which tends to decrease the load-carrying capacity of the metal. The second is the strengthening of the metal due to strain hardening which increases the load-carrying capacity of the metal. During the initial stages of the tension test, the second factor predominates, and the load-carrying capacity of the test specimen increases despite the fact that its cross-sectional area is decreasing. The rate of strain hardening, however, continuously decreases as the test progresses. This continues with all regions of the test specimen being strained and strengthened until a critical amount of strain has been attained. At this point in the test, the rate of strain hardening falls below the value necessary to offset the decrease in area, and the load-carrying capacity decreases. From this point on, the strain or deformation is localized to that region which is deformed slightly more than neighboring regions due to slight inhomogeneities in the metal or in the cross-sectional area. This point in the test is called "local instability," and the strain is the necking strain. Beyond the necking point the thinning action predominates, and the metal will support only a continuously decreasing load until fracture occurs. These features of the tension test, shown in the load-strain curve for

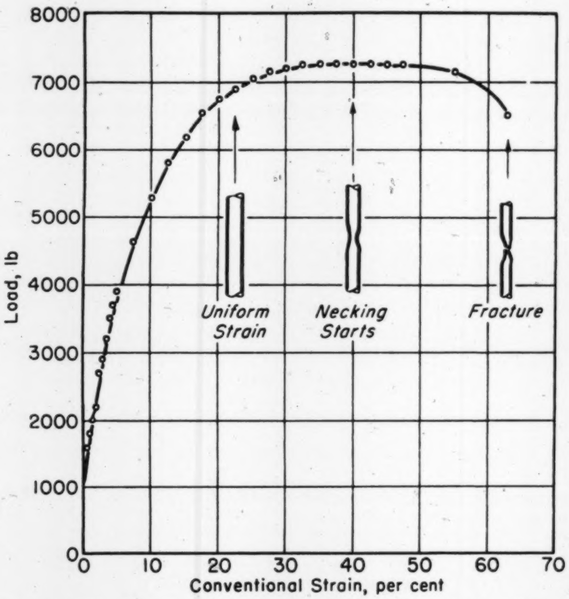

FIG. 1.—Load *versus* Strain Curve for Annealed Copper Tube ($1\frac{3}{8}$-in. Diameter, 0.055-in. Wall Thickness).

a copper tube in Fig. 1, are of value in predicting the mechanical behavior in forming metal parts.

In tube bending and in most forming operations, the necking point marks the limit of useful ductility and strength of a metal. If the strain produced by bending does not produce necking in the tube, then the bent tube will actually be stronger than the unbent and unstrained tube. A critical point in bending, then, is the strain at which "necking" occurs. This value can be easily measured and precautions taken so as not to exceed this value.

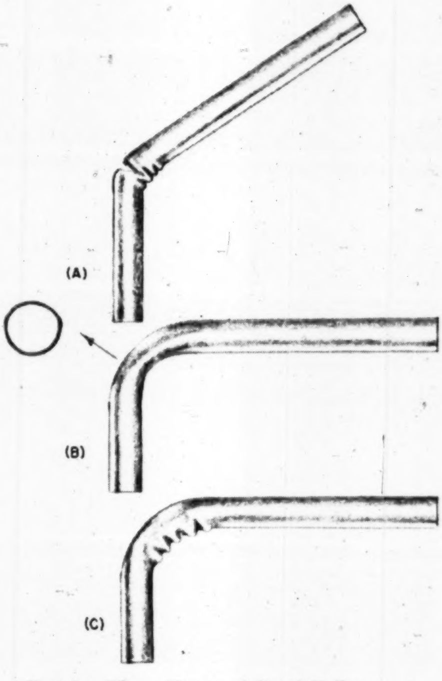

FIG. 2.—Three Types of Bend Failures.
(*A*) Necking down and cracking.
(*B*) Flattening of the outside of bend.
(*C*) Wrinkling.

Although this rationalization strongly indicates that tubes are strengthened by bending, proof of this strengthening must be obtained from actual bursting strengths of bent tubes. To date there have been no experimental results published on this subject. In addition, no analysis of the strains involved in the tube bending process has been made previously. This investigation was undertaken to supply this much needed information for copper tube.

GENERAL CONSIDERATIONS OF TUBE BENDING METHODS

In the bending of tube or pipe, there must be applied a bending force sufficiently large to stress the material beyond its elastic limit and cause plastic deformation. This bending force subjects the outside wall to a tensile stress and causes a thinning of this wall; it also subjects the inner wall to compressive stresses with a resultant thickening of the inner wall. The amounts of these deformations are dependent upon the type of bending process involved and the sharpness of the bend.

The stresses set up by the bending operation may be sufficient to cause a bend failure by one of three means:

A. A thinning down of the metal in the outside wall to such an extent that the limit of its ductility is exceeded.

B. A flattening of the outside of the bend.

C. A wrinkling or collapsing of the inner wall due to an excessive compressive stress.

These types of failures are illustrated in Fig. 2.

To minimize bend failures, the ideal material should have a high ductility, a low elastic limit, and a low rate of work hardening to extend the limits of bending; yet it should retain sufficient stiffness to prevent failure by wrinkling or collapsing of the tube. The annealed copper selected for the present tests met these requirements for bending quite satisfactorily.

In addition to the choice of material, the method of bending can have a large influence on the production of a satisfactory bend. There are five different methods of bending tube or pipe:

A. Compression bending,
B. Draw bending,
C. Roll bending,
D. Stretch bending, and
E. Ram bending.

The principal operations of these processes are sketched in Fig. 3 and have been described in several publications (**1, 3, 4, 5**). The effect that these various bending methods have on the tube bend differs mainly in the amounts of tension and compression to which the tube is subjected. This is a function of the position of the neutral axis. For compression bending, the neutral axis is shifted toward the outer radius of the tube so that approximately the outer one third is subjected to tension and the inner two thirds to compression. For draw bending the neutral axis is shifted toward the inner radius; approximately the outer two thirds of the tube, therefore, is subjected to tension. Thus thinning is considerably greater in the case of draw bending, since the strain is proportional to the distance from the neutral axis. An extreme case of thinning of the wall by bending is found in stretch bending, for which the neutral axis is on the inner radius of the bend and the entire tube is subjected to tension. In ram bending, the neutral axis lies at the center of the tube; thus equal amounts of tension and compression would be encountered.

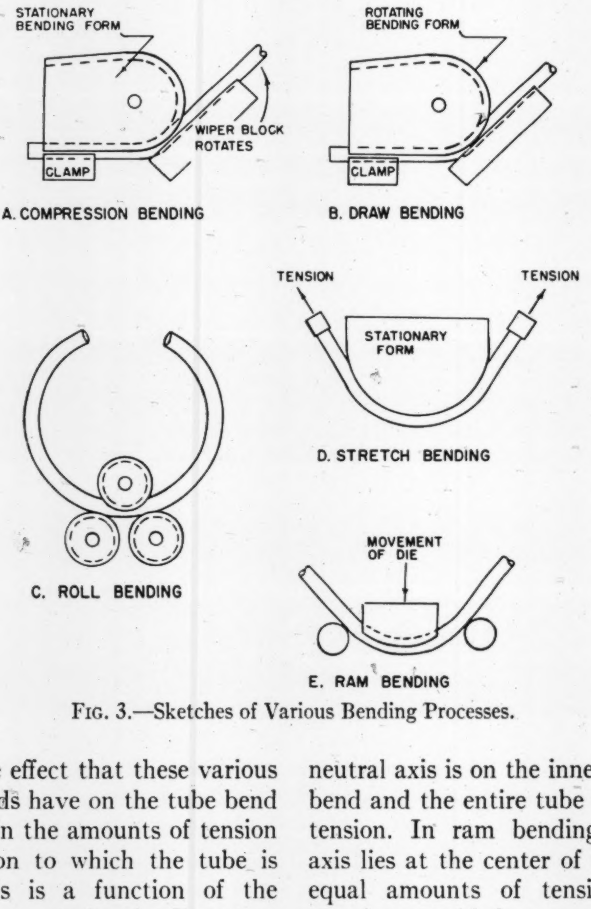
STATIONARY BENDING FORM
WIPER BLOCK ROTATES
CLAMP
A. COMPRESSION BENDING
ROTATING BENDING FORM
CLAMP
B. DRAW BENDING
TENSION
TENSION
STATIONARY FORM
D. STRETCH BENDING
C. ROLL BENDING
MOVEMENT OF DIE
E. RAM BENDING

FIG. 3.—Sketches of Various Bending Processes.

The first two types of bend failures mentioned above can be corrected by changing the position of the neutral axis. Shifting it toward the outside will reduce the thinning down of the outer wall; however, the chance of wrinkling is increased. For a shift of the neutral axis toward the inside, the reverse is true.

The third type of failure can be avoided by supporting the inside of the tube with a mandrel or with filler material. The filler material also helps prevent failure by wrinkling.

The majority of tube bending tools and machines operates either on the compression or the draw bending principles, because of the better adaptability of these methods to simple tools and to production schedules. Therefore, the bending method to be used in this investigation involved a choice between these two. The draw bending method was chosen for the following reasons:

1. Shorter radii can be bent.

2. Thin-walled tubes can be used.

3. Greater amounts of strain can be obtained.

4. It is more readily adaptable to the use of a mandrel.

5. Last, but not least, any results obtained using the draw bending method would also apply to compression bending, since for the same bend radii smaller strains and less thinning of the metal occur in compression bending.

MATERIAL AND PROCEDURE

Material:

Eight sizes of annealed copper tube and four sizes of drawn copper tube were tested in this investigation. For the annealed material, types K and L in the ½-, ¾-, 1-, and 1¼-in. nominal sizes were used. The ¾- and 1-in. sizes in types K and L were used for the drawn tubes. The tubes were manufactured using standard commercial practices and were procured in 20-ft lengths.

The sizes and tolerances for these tubes are listed in Table I, according to ASTM Specification B 251.[4] Measurements made on these tubes showed that the tolerances were met in all cases except for the wall thickness of the 1¼-in., type K annealed copper tube which was as much as 0.003 in. over the allowable tolerance. Other requirements, listed in ASTM Specification B 88,[5] such as tensile strength, ductility, hardness, and bursting strength, were met by this material.

A grid of one hundred lines to the inch was superimposed on the surface of test specimens to enable measurements of strain to be made. This grid was applied

TABLE I.—SIZES AND TOLERANCES OF COPPER TUBE.

Nominal Tube Size, in.	Type	Actual Outside Diameter, in.	Tolerance for Average Outside Diameter, in.		Wall Thickness, in.	
			Annealed	Drawn	Nominal	Tolerance
½	L	0.625	0.0025	0.001	0.040	0.0035
½	K	0.625	0.0025	0.001	0.049	0.004
¾	L	0.875	0.003	0.001	0.045	0.004
¾	K	0.875	0.003	0.001	0.065	0.0045
1	L	1.125	0.0035	0.0015	0.050	0.004
1	K	1.125	0.0035	0.0015	0.065	0.0045
1¼	L	1.375	0.004	0.0015	0.055	0.0045
1¼	K	1.375	0.004	0.0015	0.065	0.0045

NOTE.—All tolerances are plus and minus.

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[4] Specification for General Requirements for Wrought Seamless Copper and Copper-Alloy Pipe and Tube (B 251 – 54 T), 1954 Supplement to Book of ASTM Standards, Part 2, p. 154.

[5] Specification for Seamless Copper Water Tube (B 88 – 54), 1954 Supplement to Book of ASTM Standards, Part 2, p. 76

by a photographic process which has been described in the literature, but since certain refinements were necessary, the process is briefly reviewed in Appendix II.

Equipment:

The tubes were bent on a Parker 848 power-driven tube bending machine, shown in Fig. 4, which utilized the draw-bending principle. Radius blocks were used to obtain bend radii of two, four, and six times the outside diameter of the tube for each of the four sizes tested.[6]

Standard mandrels were used for the $4D$[7] and $6D$ bends. A low melting point alloy[8] was used to prevent collapsing of the tube during bending to radii of $2D$.

The operation of the bending machine has been described in several articles mentioned previously. Briefly, the procedure is to clean and oil the inside of the tube, clamp it securely to the radius block, place the mandrel in position, bring the pressure die into position, and then rotate the radius block to produce the bend.

Tension tests on the full-scale tube specimens were made on a 60,000-lb capacity Baldwin-Southwark tension machine.

Hydraulic pressure for testing the bursting strength of the tube bends was obtained from the hydraulic system of a 10,000-lb capacity Riehle tension machine. This equipment is shown in Fig. 6.

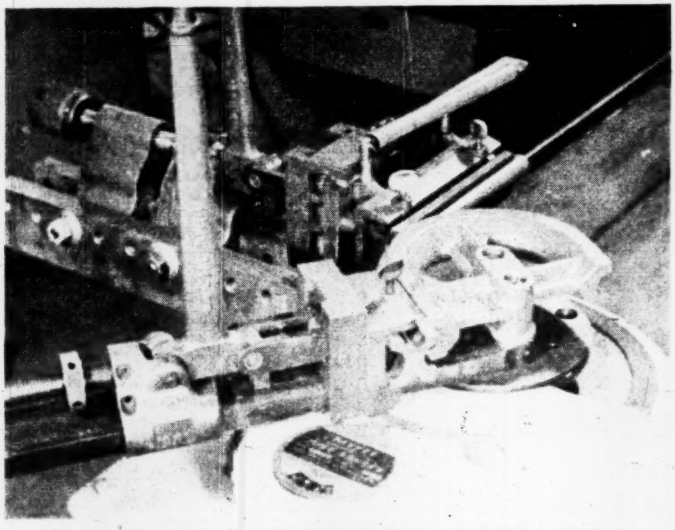

FIG. 4.—Tube Bending Equipment (Parker 848 Tube Bender).

Procedure:

The strains resulting from bending the tubes were determined from the changes in the gage lengths of the photogrid measured before and after bending, using a microscope equipped with a filar micrometer. Since the longitudinal strains along the length of the bend were constant, measurements were made over relatively large gage lengths of 0.10 in., or 10 divisions on the photogrid. By using this longer gage length, a greater degree of accuracy was possible. Circumferential strains on the tube were not constant and, therefore, measurements were made over short gage lengths of 0.01 in. or 1 division on the photogrid. For increased accuracy, these measurements were plotted and the minimum values taken from the plot.

---

[6] Two concepts exist for the measurement of the bend radius. In one the bend radius is measured to the center line of the tube (R in Fig. 5). For the other it is measured to the inside of the tube (R_2 in Fig. 5). The former was used for this investigation since it enjoys a wider usage.

[7] The expression $4D$ refers to a bend radius of four times the outside diameter of the tube: $6D$ refers to a bend radius of six times the outside diameter of the tube, etc.

[8] Lipowitz alloy with a melting point of about 160 F was used. Its composition was 50 per cent bismuth, 27 per cent lead, 13 per cent tin, and 10 per cent cadmium.

Full-scale tension tests were made on tube lengths of at least four times the outside diameter of the tubes, excluding the length required for the grips of the tension machine. Plugs were used to prevent collapsing in the grips. Measurements of the photogrid were made on lengths outside of the necked-down area surrounding the fracture to determine the necking strain for the material. Other full-scale specimens with photogrids were strained in tension until a maximum in the load indicated that the necking strain had been reached, and then measurements were made. Still other tension tests were conducted on sections cut from the tubes in both the longitudinal and transverse directions.

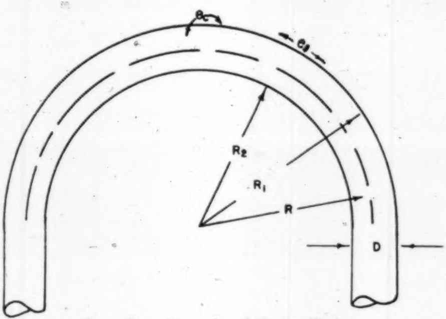

FIG. 5.—Sketch of Bent Tube.

D—tube outside diameter.
R—bend radius (to centerline of tube).
R_1—outer radius of bend.
R_2—inner radius of bend.
ϵ_{l1}—longitudinal bending strain on the surface of R_1.
ϵ_{c1}—circumferential bending strain on the surface of R_1.
ϵ_{l2}—longitudinal bending strain on the surface of R_2.
ϵ_{c2}—circumferential bending strain on the surface of R_2.

Bent tubes which were tested under hydraulic pressure were attached to the hydraulic lines with flareless "bite"-type fittings as illustrated in Fig. 7. This type of fitting was used since it allowed assembly onto a curved section of tube, whereas some straight length would have been necessary for the use of a flare-type fitting. In testing the tube bends, it was necessary to eliminate all straight lengths of tube since the test section would have invariably failed in this straight portion (see Fig. 8).[9]

The test sections were attached to the hydraulic system of the tension testing machine and loaded to the bursting pressure, with pressures being measured with a Bourdon-type gage. Measurements were made of the tube diameter before and after testing.

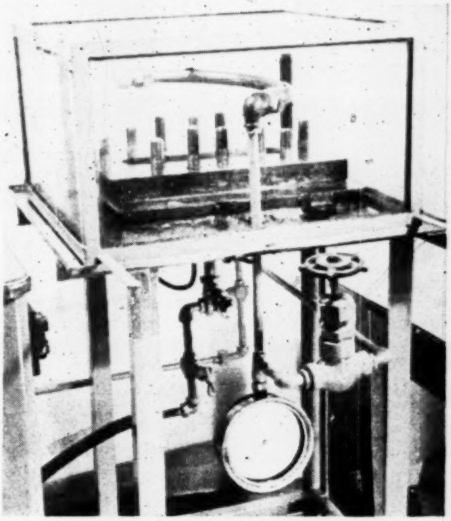

FIG. 6.—Bursting Equipment.

RESULTS AND DISCUSSION[10]

The longitudinal strains at the outer fiber, ϵ_l^o, inner fiber, ϵ_l^i, and center line,

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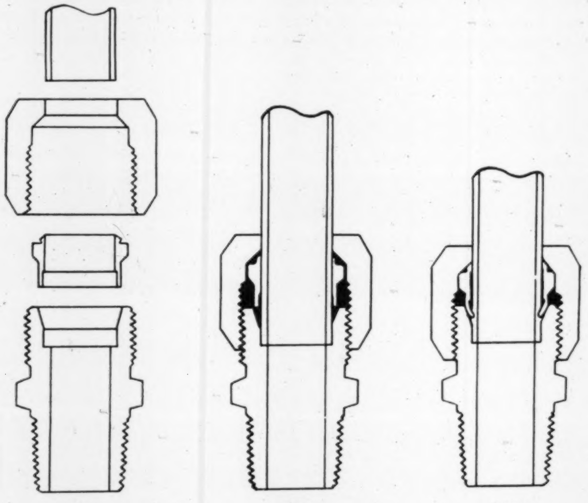
[9] This test, in itself, is proof that the bend is stronger for the conditions under study, but it does not show how much stronger.

[10] This section pertains only to the research on annealed copper tube. Some tests conducted on hard-drawn copper tube are covered in Appendix A.

ϵ_l^c, are plotted in Fig. 9 as a function of the bend radius.[11]

The symmetry of these strains on the outer and inner radii and the presence of little or no strain on the center line of the bend suggest that the neutral axis of the bend lies close to the center line. Although draw bending should displace the neutral axis toward the inner radius of the bend, there is a slight collapsing of the tube in the radial direction in spite of the mandrel or filler material which tends to offset this shift. An equation derived with the assumption that the neutral axis of the bend lies on the center line of the tube fits the measured values of strain adequately.



(*a*) Unassembled. (*b*) Assembly. (*c*) Assembled.

FIG. 7.—Flareless Bite-Type Fitting.

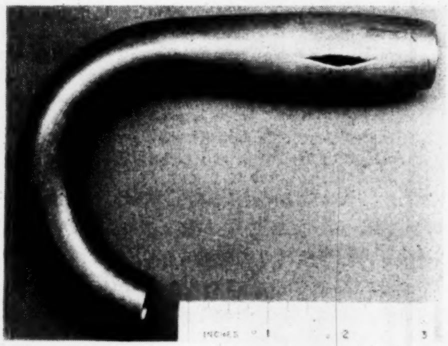


FIG. 8.—Bursting Test Specimen Showing Failure Occurring in Unbent Section Rather Than in Bent Section.

This equation may be derived as follows: By reference to Fig. 5, it may be seen that circumferential distance along the outer surface of the bend is πR_1, while the distance along the center line is πR. The longitudinal strain on the outer surface may be written as follows:

---

[11] Previous work (6) describing bending of rectangular aluminum bars has shown that a certain minimum bend angle is necessary to develop the full amount of strain associated with a given bend radius. In Figs. 10 and 11 variations in longitudinal and circumferential strains for the $\frac{7}{8}$-in. diameter tube have been plotted along the length of the bend for the outer radius. These measurements indicate that the maximum strain is reached after a bend length of from 2 to 3 in. This length would be longer or shorter for other tubes in proportion to their diameters. Since the lengths of all bends made to radii of two, four, and six times the tube diameter are all proportionately longer than this length, the maximum strains are obtained in all cases.

$$\epsilon_l^o = \frac{\pi R_1 - \pi R}{\pi R} = \frac{R_1 - R}{R}$$

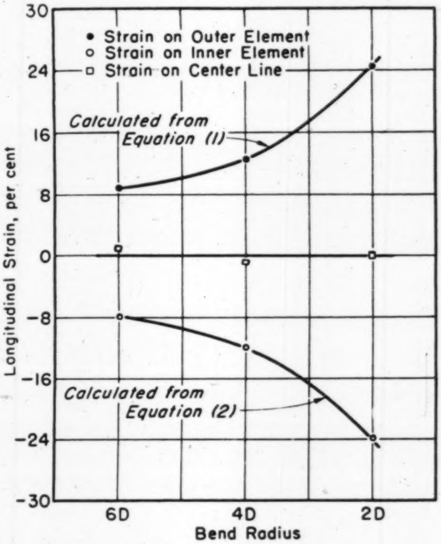


FIG. 9.—Longitudinal Strains on the Outer and Inner Radii and on the Center Line of Bent Tubes.

However, $R_1 = R + \frac{1}{2}D$ and therefore:

$$\epsilon_l^o = \frac{D}{2R}$$

or in terms of percentage:

$$\epsilon_l^o = \frac{50D}{R}\ \% \qquad (1)$$

where:

ϵ_l^o = longitudinal strain, per cent,
D = tube diameter, in., and
R = bend radius, in.

By a similar procedure the expression for the longitudinal strain at the inner surface of the bend is:

$$\epsilon_l^i = \frac{50D}{R}\ \% \qquad (2)$$

The longitudinal strains derived from Eqs 1 and 2 are plotted in Fig. 9 along with the experimentally measured strains. The agreement between the two is good.

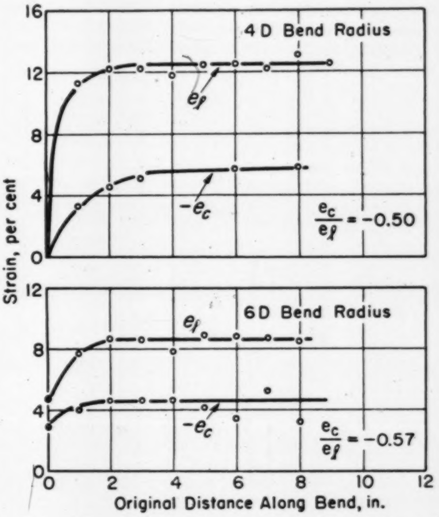


FIG. 10.—Distribution of Longitudinal and Circumferential Strains Along the Outer Radius of Tubes Bent to Radii of 4*D* and 6*D*.

Figure 12 is a plot of the longitudinal strain at the outer fiber, ϵ_l^o, the circumferential strain at the outer fiber, ϵ_c^o, and the thickness strain at the outer fiber, ϵ_r^o, for tubes bent to various radii. The three strains at any given bend radius are such that the longitudinal natural strain[12] is equal to twice the cir-

---

[12] Natural strain, ϵ, is defined so that increments of natural strain are calculated in terms of the instantaneous length, whereas increments of conventional strain, e, are expressed with reference to the original length. Natural strain may be expressed mathematically as follows:

$$d\epsilon = \frac{dl}{l} = \frac{de}{1+e}$$

or:

$$\epsilon = \ln\frac{l}{l_0} = \ln(1+e)$$

TABLE II.—MEASURED VALUES OF LONGITUDINAL, CIRCUMFERENTIAL, AND RADIAL STRAIN IN TUBE BENDING.

Bend Radius	Longitudinal Strain, per cent	Circumferential Strain, per cent	Radial Strain, per cent
2*D*...........	24.5	−10.3	−10.7
4*D*...........	12.5	−5.7	−5.2
6*D*...........	8.8	−4.1	−4.8

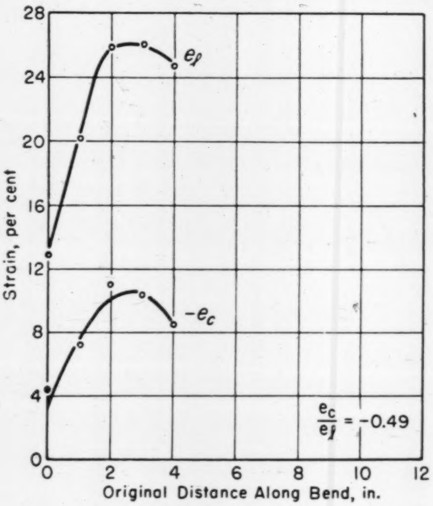


FIG. 11.—Distribution of Longitudinal and Circumferential Strains Along the Outer Radius o a Tube Bent to a Radius of 2*D*.

cumferential or radial natural strain, but opposite in sign:

$$\epsilon_l = -2\epsilon_c = -2\epsilon_r$$

This condition describes a uniaxial tension strain state. There is some deviation from this ideal condition at low bend radii (less than 2*D*) due to difficulties in strain measurements for bends made to such small radii.[13] Such bends are not recommended by the manufacturers of tube benders.

If the decrease in thickness of wall shown in Table III were represented as a reduction in tensile strength of this wall, it would amount to only an 11 per cent decrease for the 2*D* bend, 6 per cent for the 4*D* bends, and 4 per cent for the 6*D* bends. Of course, as will be explained, no loss of strength accompanies the reduction in thickness.

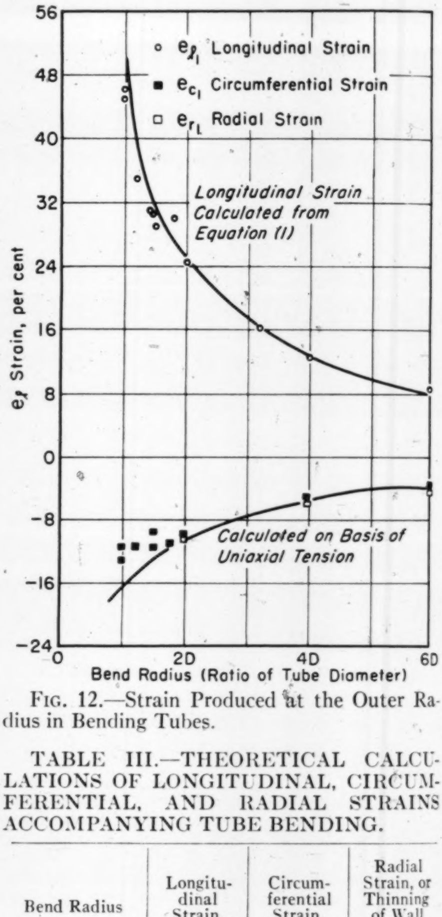


FIG. 12.—Strain Produced at the Outer Radius in Bending Tubes.

TABLE III.—THEORETICAL CALCULATIONS OF LONGITUDINAL, CIRCUMFERENTIAL, AND RADIAL STRAINS ACCOMPANYING TUBE BENDING.

Bend Radius	Longitudinal Strain, per cent	Circumferential Strain, per cent	Radial Strain, or Thinning of Wall Thickness, per cent
2*D*...........	25	−10.6	−10.6
4*D*...........	12.5	−5.7	−5.2
6*D*...........	8.8	−4.1	−4.8

Tension tests made on the full-scale straight length copper tubes are reported in Table IV. These results are the average of two tests for each size of tube. All of these tensile properties meet the requirements of specifications for annealed copper tubes. The necking strains which have been included in the results were obtained from measurements on the photogrid (originally 100 lines-to-the-inch) at a position removed from the necked portions of the specimens.[14]

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[13] As discussed earlier, it is possible that the length along the bend for such small radii may not be sufficient to create the maximum strain attainable for these radii.

TABLE IV.—RESULTS OF TENSION TESTS ON ANNEALED COPPER TUBES.

Tube Diameter, in.	Wall Thickness, in.	Tensile Strength, psi	Per cent Elongation in Gage Length of 2 × Diameter	Necking Strain, per cent
⅝	0.040	32 800	33.5	38
⅝	0.049	34 600	44.7	32
⅞	0.045	33 000	38.0	31
⅞	0.065	32 900	37.4	44
1⅛	0.050	33 500	49.1	42.4
1⅛	0.065	35 000	50.8	46.0
1⅜	0.055	32 700	48.1	39.4
1⅜	0.065	34 700	51.9	42.8

TABLE V.—ANNEALED COPPER TUBES TESTED IN TENSION TO THE NECKING STRAIN.

Tube Diameter, in.	Wall Thickness, in.	Necking Strain, per cent
⅝	0.049	46
⅞	0.045	34.3
1⅛	0.050	40.2
1⅜	0.064	43.3

The necking strains obtained from additional tension tests on full-scale tubes which were tested only up to the maximum load are reported in Table V. Thus, necking-down and fracture for these specimens were eliminated, and strain measurements taken on the photo grid gave the necking strain.

Tension tests were also made on flat specimens cut longitudinally from a tube 1⅜ in. in diameter and with a 0.055-in. wall thickness. The specimens varied in width from 0.1 to 1 in. The results of these tests are listed in Table VI.

On the basis of the results of all these tension tests, the necking strain is approximately 40 per cent for annealed copper. This is in approximate agreement with the value found by Sachs and Lubahn (**8**). As has been explained earlier, the necking strain represents what is actually the limiting ductility of the metal in a forming operation.

It has been proven by many investigators (**9, 10, 11, 12**) that the necking strain is dependent upon the stress state of a forming operation. However, the stress state at the outer fiber in tube bending has been shown to be approximately one of uniaxial tension, and the necking strain for bending should be the same as for the tension test. Since the outer fiber in tube bending deforms in pure tension, it should not neck below a strain of 40 per cent for annealed copper, and in view of the support of adjacent material which has undergone less strain than the outer fiber, necking may not occur until more than 40 per cent.

TABLE VI.—RESULTS OF TENSION TESTS ON LONGITUDINAL SPECIMENS CUT FROM A 1⅜-IN. DIAMETER TUBE WITH AN 0.055-IN. WALL THICKNESS.

Specimen Width, in.	Tensile Strength, psi	Necking Strain, per cent
0.100	33 500	33.2
½	33 800	36.6
¾	33 700	37.6
1	33 700	36.2

The maximum strain obtained in bending tubes on the standard radius blocks used in this investigation was only 25 per cent. This was for a bend radius of two times the tube diameter, which was the severest bend recommended for annealed copper by the manufacturer of the tube bender. Thus the strains produced by bending to any of the recommended bend radii are considerably less than the necking strain for annealed copper. Since the strength of the bent and strained metal is known to increase up to the necking point, tubes bent to radii which involve strains less than the necking strain should all be stronger than the unbent tube.

---

[14] The strain at positions removed from the necked portion of a tensile specimen has been shown by Lubahn (**7**) to be equal to the necking strain.

Some bends were made to radii less than two times the diameter, but without using standard radius blocks; consequently perfect bends were not obtained. For these bends, strains in excess of the necking strain and as high as 46 per cent were measured. In each of these cases the most severely strained region, which under other conditions would have necked-down and failed, was prevented from doing so by the adjacent material which had not reached the necking strain. As an example of this restraining effect, the variation of longitudinal strains around the circumference of a tube bent to a radius of 4*D* is shown in Fig. 13. Thus the necking strain may not be so critical as had been expected for the bending of tubes.

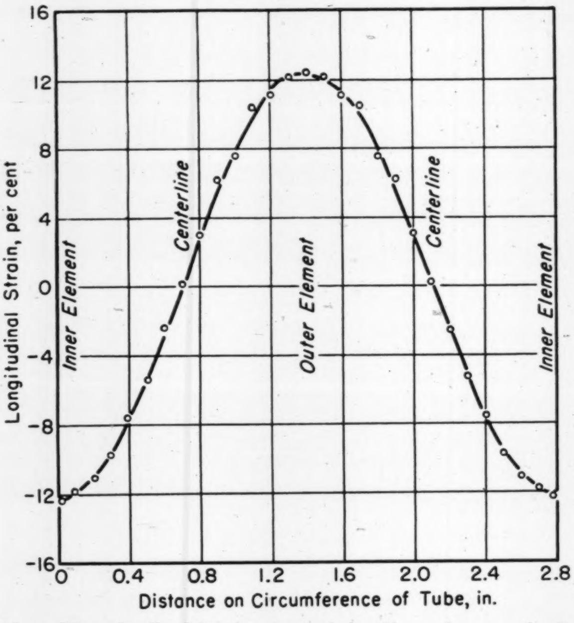

FIG. 13.—Distribution of Longitudinal Strains Around the Circumference of a Bent Copper Tube.

Since no necking has been observed in any of the bent tubes, the bursting strengths of all these tubes should be greater than the straight lengths for all the bends made in this investigation.

The equation showing the dependence of the bursting pressure of a tube on the

TABLE VII.—CALCULATED BURSTING PRESSURES OF ANNEALED COPPER TUBES.

Tube Diameter, in.	Wall Thickness, in.	Tensile Strength, psi	Calculated Bursting Pressure, psi
$\frac{7}{8}$	0.045	32 000	3470
$\frac{7}{8}$	0.065	34 400	5510
$1\frac{1}{8}$	0.050	32 400	3010
$1\frac{1}{8}$	0.065	35 000	4290
$1\frac{3}{8}$	0.055	33 500	2790
$1\frac{3}{8}$	0.065	34 200	3400

TABLE VIII.—BURSTING STRENGTHS OF ANNEALED COPPER TUBES AFTER BENDING.

Tube Diameter, in.	Wall Thickness, in.	Bend Radius	Bursting Pressure, psi	Bending Strain, per cent	Fiber Stress Calculated from Bursting Pressure, psi
5/8	0.040	1*D*	4820	44.9	...
5/8	0.040	1.4*D*	4510	31.3	...
5/8	0.040	1.7*D*	4320	18.4	...
5/8	0.040	2*D*	4435	25.0	32 400
5/8	0.040	4*D*	3850	13.0	28 100
5/8	0.040	6*D*	3770	8.2	28 000
5/8	0.040	Straight	3535	...	25 900
5/8	0.049	1.1*D*	5350	37.8	...
5/8	0.049	1.5*D*	5300	...	...
5/8	0.049	2*D*	4800	25.4	28 200
5/8	0.049	2.5*D*	5300	20.1	...
5/8	0.049	4*D*	5050	14.2	29 700
5/8	0.049	6*D*	4930	8.1	29 000
5/8		Straight	4710	...	27 700
7/8	0.045	1*D*	3680	...	...
7/8	0.045	1.2*D*	3650	35.0	...
7/8	0.045	1.5*D*	3650	29.0	...
7/8	0.045	1.8*D*	3410	30.2	...
7/8	0.045	2*D*	3490	25.3	32 200
7/8	0.045	3.2*D*	3170	16.3	...
7/8	0.045	4*D*	3300	11.7	30 400
7/8	0.045	6*D*	3130	6.9	28 900
7/8	0.045	Straight	2840	...	26 200
7/8	0.065	1*D*	5750	46.3	...
7/8	0.065	1.5*D*	5600	30.7	...
7/8	0.065	1.8*D*	5050	30	...
7/8	0.065	2*D*	4940	24.6	30 600
7/8	0.065	3.2*D*	5030	15.9	...
7/8	0.065	4*D*	4975	12.9	31 000
7/8	0.065	6*D*	4840	8.5	30 200
7/8	0.065	Straight	4590	...	28 600
1 1/8	0.050	2*D*	3145	...	33 800
1 1/8	0.050	4*D*	2890	12.0	31 100
1 1/8	0.050	6*D*	2890	7.8	31 100
1 1/8	0.050	Straight	2600	...	28 000
1 1/8	0.065	2*D*	4360	25.4	35 500
1 1/8	0.065	4*D*	4105	12.9	33 500
1 1/8	0.065	6*D*	3925	7.8	32 000
1 1/8	0.065	Straight	3660	...	29 800
1 3/8	0.055	2*D*	2570	25	30 800
1 3/8	0.055	4*D*	2575	12.0	30 900
1 3/8	0.055	6*D*	2670	8.3	32 000
1 3/8	0.055	Straight	2450	...	29 400

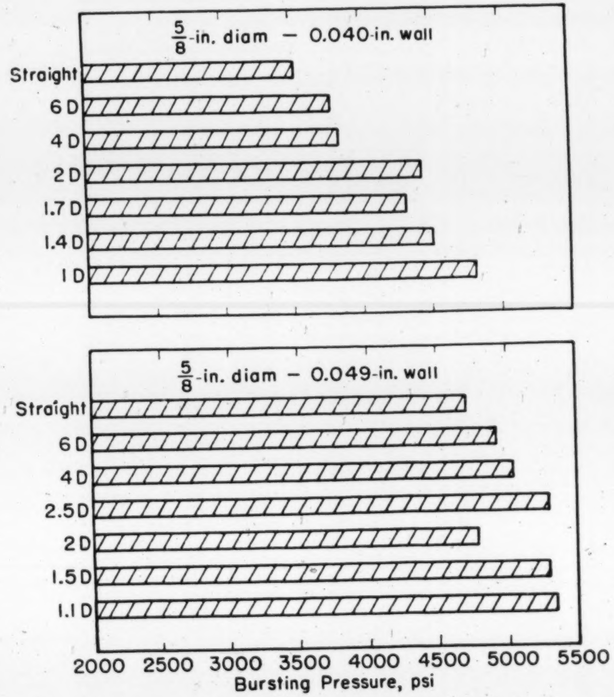

FIG. 14.—Effect of Bend Radius on the Bursting Pressure of $\frac{5}{8}$-in. Diameter Annealed Copper Tube.

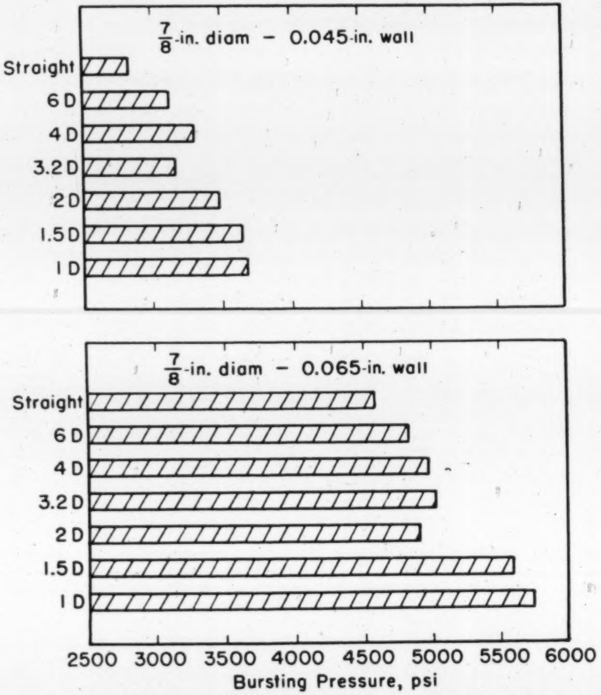

FIG. 15.—Effect of Bend Radius on the Bursting Pressure of $\frac{7}{8}$-in. Diameter Annealed Copper Tube.

tensile strength of the material is as follows:

$$P = \frac{2St}{D} \qquad (3)$$

where:

P = bursting pressure, psi,
S = tensile strength, psi,
t = wall thickness, in., and
D = average tube diameter, in.

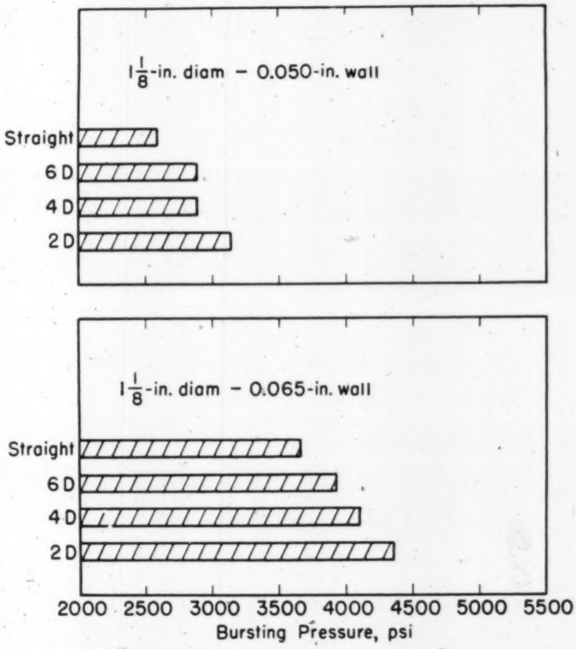

FIG. 16.—Effect of Bend Radius on the Bursting Pressure of $1\frac{1}{8}$-in. Diameter Annealed Copper Tube.

The tensile strength involved in this equation is not the longitudinal tensile strength of the tube; instead, it is the transverse or circumferential tensile strength of the tube. Therefore, tests were conducted on specimens cut from the tube in the circumferential direction. To do this, rings were taken from the tube, cut longitudinally, and straightened out. The results of these tests are reported in Table VII. According to these tests, the transverse tensile strength is slightly higher than the longitudinal tensile strength. This difference is probably due to the work hardening involved in straightening the transverse section cut from the tube. The expected bursting pressures of the tubes were calculated by substituting the transverse tensile strengths in Eq 3. These results are included in Table VII.

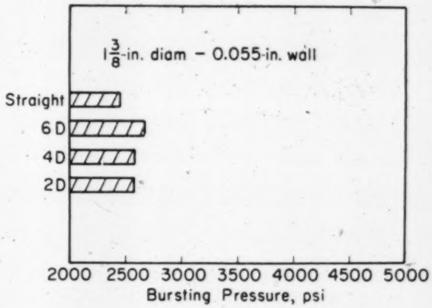

FIG. 17.—Effect of Bend Radius on the Bursting Pressure of $1\frac{3}{8}$-in. Diameter Annealed Copper Tube.

The bursting strengths of the copper tubes after bending are summarized in Table VIII. A graphical comparison of these strengths with the strengths of the straight tube is made in Figs. 14 to 17. In all cases the tube is stronger after bending than it was before bending. These data, then, support the supposition made previously that the bent tube would have a higher bursting strength after bending than it had before. In fact, the bursting strength becomes increasingly greater with decreasing bend radii up to and including the smallest radius tested. Since the bending strain is larger for smaller bend radii, the bursting strength of the bent tubes may also be said to increase with increasing bending strain.

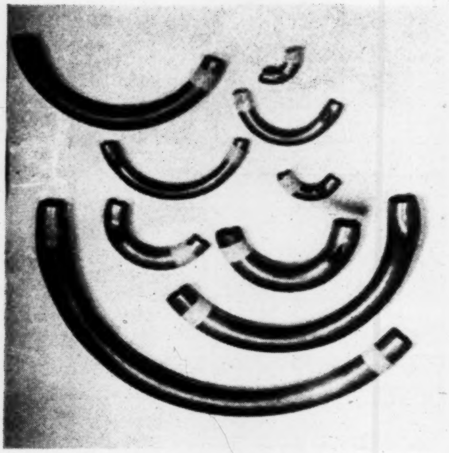

FIG. 18.—Bent Copper Tubes After Bursting Test.

This increase in bursting pressure is attributed to the increase in tensile strength brought about by the bending operation. These tensile strengths or fiber strengths as calculated from Eq **3** have been added to Table VIII.

An examination of the tubes after bursting showed that in every case except one[15] the failure occurred on the neutral axis of the bend (see Fig. 18). As discussed earlier, this portion of the tube undergoes only a small amount of deformation during the bending process. It would, therefore, be expected that this portion of the bent tube would exhibit the same properties as the unbent tube. However, due to some small amount of cold work done on this area and due to the restraining effect of the surrounding metal which has been cold-worked during bending, the strength of that part of the bent tube has been raised above that of the unbent tube.

Certainly it must be evident from the position of these failures that the weakest section of the bent tubing is at the neutral axis and the sections that have been cold-worked are stronger even though they may have been thinned down in the bending process. The location of the failure adds additional support to the supposition that bending a tube strengthens it rather than weakens it due to the reduction in its thickness.

Although the primary objective of this investigation had been accomplished with the testing of bent sections of copper tube and the establishment of the fact that these are actually stronger than the original tube, the strength of the region most severely strained during the bending operation was still unknown. This is the material on the outer circumference of the bend which during the straining is reduced in cross-section, resulting in a thinner wall at this point of the tube. As noted earlier, the tube always failed on the neutral axis of the bend where no appreciable straining had taken place. Thus the material under question had not as yet been tested to its limit.

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[15] For this one exception, the failure occurred on the outer radius, and it is probable that an imperfection existed at this point causing premature failure.

In order to test the strength of the material which constitutes the outer circumference of the bend, the remainder of the test section must be at least as strong. To produce this condition, a $1\frac{1}{8}$-in. diameter annealed tube was strained in a tension machine to its necking point. This amount of strain was chosen since it represented the maximum thinning of the metal without damage by necking. The amount of the strain measured by means of the photogrid was 40 per cent. The wall thickness had been reduced from a thickness of 0.050 to 0.0415 in. The tube was then subjected to a bursting test.

The bursting pressure of this strained tube was 4400 psi, while the bursting pressure for the annealed tube with an 0.050-in. wall was only 2600 psi. Actually, the increase in strength is not due to the material alone. A part of this increase in strength is due to the decrease in tube diameter. Its diameter after straining was only 0.955 in. By reference to Eq 3, it may be seen that the pressure is inversely proportional to the diameter of the tube.

A more equitable basis for comparison would be through a conversion of the bursting pressures to tensile strengths of the respective tubes. On this basis the annealed tube had a tensile strength of 28,000 psi. Using the original wall thickness and the final tube diameter, the strained tube had a tensile strength of 40,500 psi. This is a considerable improvement in strength even though the original wall thickness was used in computing this tensile strength. If the actual wall thickness were used, the tensile strength would be 50,600 psi. Although the ductility of this strained material was not determined, it was sufficiently high to allow flaring considerably in excess of that necessary to adapt it to a flare-type fitting.

CONCLUSIONS

1. Strain measurements of annealed copper tubes bent by the draw bending process indicate that the neutral axis lies on the center line and permits the derivation of an equation relating the longitudinal bending strain and the bend radius.

2. Strain measurements show that a stress state of uniaxial tension exists for the outer fiber of a tube in bending.

3. Thus the necking strain for this outer fiber should be the same as found in ordinary tension tests on the copper tubes, that is, 40 per cent.

4. The strains resulting from bends made to two, four, and six times the tube diameter did not attain this strain; hence no necking was to be expected nor was it found. The strength of the tube should therefore be increased by bending.

5. Tests show that the bursting strength of a copper tube is actually increased by bending the tube.

6. Failure in bursting tests always occurs close to the neutral axis of the bend, indicating that the most severely strained and thinnest section of the bent tube is not the weakest section.

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APPENDIX I

TESTS ON HARD-DRAWN COPPER TUBES

Some tests were made on hard-drawn copper tubes $\frac{7}{8}$ and $1\frac{1}{8}$ in. in diameter to provide information on the effect of bending on the strength of this temper.

Tension tests of the hard-drawn copper tubes were made to determine the ductility and tensile strength. The results of these tests are reported in Table IX. The $\frac{7}{8}$-in. diameter tube with an 0.045-in. wall thickness exhibited the highest tensile strength (69,500 psi) and the lowest ductility (7.2 per cent), probably due to more severe drawing. The lowest tensile strength was 60,000 psi, compared to the 48,000 psi minimum allowed by ASTM Specification B 88.[5] The highest ductility or necking strain was 9.5 per cent.

It may be seen from Fig. 9 that the longitudinal bending strains for bends of two, four, and six times the tube diameter of annealed copper are 24.5, 12.5, and 8 per cent, respectively. In view of this fact, it may be expected that the hard-drawn copper tube could be bent successfully only to a bend radius of six times the diameter. Even for this bend radius, the necking strain of the material is approximately equalled by the bending strain, and fracture in bending is likely. The hard-drawn tubes cracked on every attempt at bending to a radius of twice the diameter. For a radius of four times the diameter, some successful bends were made, whereas none of the tubes cracked on bending to a radius of six times the diameter. This is further proof that the conditions involved in the bending of a tube will allow bending strains in excess of the necking strain of the metal as determined from a tension test. The reason for this apparent increase in ductility of the metal is the same as discussed previously, that is, the failure may be prevented by the restraining effect of the adjacent mate-

TABLE IX.—TENSION TESTS ON HARD-DRAWN COPPER TUBES.

Tube Diameter, in.	Wall Thickness, in.	Tensile Strength, psi	Necking Strain, per cent
$\frac{7}{8}$	0.045	69 500	7.2
$\frac{7}{8}$	0.065	61 900	7.8
$1\frac{1}{8}$	0.050	65 000	...
$1\frac{1}{8}$	0.065	60 000	9.5

rial which has not reached the necking strain.

Since, in bending the hard-drawn copper tubes, strains of a magnitude equal to or greater than the necking strain of the material (as determined from a tension test) have been produced, it may be expected that the strengths of these bent tubes have been decreased rather than increased as they had been for the annealed copper tubes. The results of bursting tests on the hard-drawn tubes are reported in Table X. Unfortunately, these tests were limited to a maximum pressure of 6000 psi by the capacity of the bursting equipment. Tests to a maximum pressure were obtained only in the case of the 1⅛-in. diameter tube with a wall thickness of 0.050 in. For this size the bursting pressure of the bent tubes was slightly lower than that of the unbent tube. All other tests were carried out to the maximum pressure of 6000 psi.

The fiber or circumferential stresses in the tube have been calculated from the bursting test pressures and have been added to Table X. All of these test pressures produce fiber stresses which are quite high, although not sufficiently high in most cases to cause failure. The stresses are, in fact, at least six times that required by ASTM Specification B 88 for internal pressure tests on copper water tube. Evidently even the hard-drawn tubes have not been adversely affected by bending (provided a successful bend can be made) since they meet the requirements of this specification.

TABLE X.—BURSTING PRESSURE OF HARD-DRAWN COPPER TUBES.

Tube Diameter, in.	Wall Thickness, in.	Bend Radius	Bursting Pressure, psi	Fiber Stress Produced by Bursting Pressure, psi
⅞	0.045	4*D*	>6000	>55 400
⅞	0.045	6*D*	>6000	>55 400
⅞	0.045	Straight	>6000	>55 400
⅞	0.065	4*D*	>6000	>37 400
⅞	0.065	6*D*	>6000	>37 400
⅞	0.065	Straight	>6000	>37 400
1⅛	0.050	4*D*	....	....
1⅛	0.050	6*D*	5450	58 600
1⅛	0.050	Straight	5650	60 700
1⅛	0.065	4*D*	>6000	>48 000
1⅛	0.065	6*D*	>6000	>48 000
1⅛	0.065	Straight	>6000	>48 000

APPENDIX II

APPLICATION OF PHOTOGRID PROCESS

The grid of 100 lines to the inch was applied to the surface of specimens by a photographic process as previously described (**13, 14**). The metal surface was cleaned of grease and oxide with a fine abrasive and steel wool. It was then washed in water and thoroughly dried. A sensitizing solution, of the composition shown below, was applied as a thin coat to the specimen with a piece of cotton.

	PARTS BY WEIGHT
Water	28
Photoengraver's glue	4
Ammonium or potassium bichromate	1
Strong ammonia water	¼

The specimen was immediately dried with a blower. Satisfactory results have also been obtained by spraying the solution. For spraying, the solution is diluted with four parts of water and four parts of alcohol.

The following special techniques were used in adapting the exposure and development of the emulsion to the tubular specimens of this research. The negative was wrapped tightly around the tube and held in place with cellulose tape. It is important that close contact be maintained, for a diffuse grid line and sometimes none at all will result where contact is not intimate. The specimen was then placed between centers and rotated at a speed of 1 rpm (see Fig. 19).

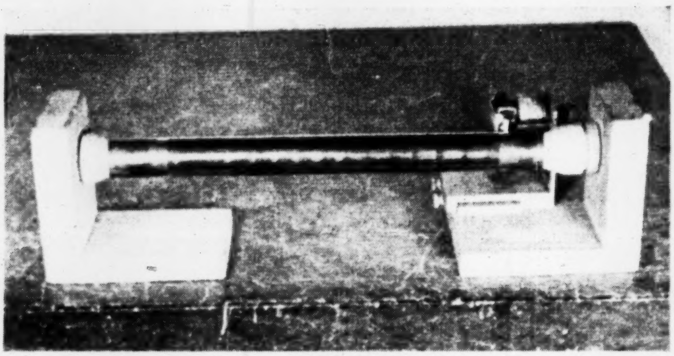

FIG. 19.—Equipment for Exposure of Photogrid.

The exposure was made using an arc light 24 in. from the specimen for a time of about 10 min. The unexposed coating was then washed off under warm water (120 to 160 F). Development was brought about by immersion into a hot dye bath (120 to 150 F) for 1 to 2 min. The dye bath was made up of 1 oz of black dye dissolved in 1 pt of water. The exposure and development should be as soon as possible after application of the emulsion.

DISCUSSION

MR. G. H. BOHN[1] (*presented in written form*).—It would appear that the authors have assumed that the outer wall will thin in proportion to the bending radius. This does not seem to be correct both theoretically and actually.

Following is quoted from "Forming of Austenitic Chromium-Nickel Stainless Steels" by International Nickel Co., Inc.:

"In a bent tube, the outside fibers of the metal are subjected to stretching while the inside fibers are subject to shrinking. Both this stretch and shrink, for a large arc of bend, are given approximately by the relation:

$$e = D/2R \qquad (1)$$

where:

e = the strain (stretch or shrink),

D = the outside diameter of the tubing, and

R = the bend radius.

Metal subjected to stretching will be reduced in thickness, T approximately by the amount ΔT, or by the following percentage:

$$\frac{\Delta T}{T} \times 100 = \left(1 - \frac{1}{\sqrt{1+e}}\right) \times 100 \qquad (2)$$

For example, a comparatively sharp bend (for example, $R/D = 1.3$) exhibits a stretch e of 38.5 per cent and a decrease in wall thickness ($\Delta T/T$) of 15 per cent. A mild bend (for example, $R/D = 20$) exhibits only 2.5 per cent stretch and 1 per cent decrease in wall thickness. For certain applications, the change in wall thickness during bending must be considered."

Measurements that we have made show that the outer wall thins less than the $D/2R$.

The second comment is that in actual service where there is velocity, rupture generally occurs in the thinner outer wall of the bent section because of an erosion effect. We have sections that show this effect. On outlet lines of compressors where the vapor is condensing, this effect is most outstanding. The rupture tests were made under static conditions where this effect is not noticed.

MR. LEO SCHAPIRO.[2] — In Fig. 12, the authors compared the longitudinal strain with various bend radii against circumferential and radial strains. Will they please clarify how the circumferential and radial strains were measured?

In tube bending, it quite often happens that on the neutral axis some flattening occurs, so that in pressurizing to burst, the flattened neutral axis will breathe, so to speak, thereby creating a greater tension on the neutral axis and perhaps being the reason for bursting always occuring in the neutral axis.

Will the authors please comment on the flattening in this case?

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[1] Linde Air Products Co., A Division of Union Carbide and Carbon Corp., Tonawanda, N. Y.

[2] Chief Metallurgist, Santa Monica Division, Douglas Aircraft Co., Santa Monica, Calif.

MR. JOSEPH W. MARIN.[3] — Did the authors attempt to interpret the fractures obtained by using any of the theories of plasticity?

MR. W. M. BALDWIN, JR., (*author*). — We were pleased to have the many interesting comments and questions from the various discussors.

I do not believe there is any discrepancy between Mr. Bohn's views and ours. We do not assume that the outer wall thins in proportion to the bending radius. Our experimentally determined data are in complete accord with the equations Mr. Bohn quotes. Furthermore, his Eq 1 is the same as our Eq 1, and his Eq 2 follows from his Eq 1 by virtue of the equation (unnumbered) given toward the bottom of the left-hand column of page 1030 of the paper. The minor difference in the equations which Mr. Bohn quotes and the equations in our paper arise merely from the manner in which the various strains have been defined. In this respect, he may refer to the footnote No. 12. To reassure himself, Mr. Bohn may, for example, read off any of the values in Fig. 12 — both longitudinal strains and radial strains — and substitute them in the formulae he quotes, and he will note that the equations are satisfied.

Mr. Bohn's comments relative to erosion effect of the outer wall are well taken.

Mr. Bohn notes that fracture always occurred on the neutral axis of the bend where the metal presumably is still in the annealed condition, and he justifiably wonders why the bursting pressure should be greater for the bend than for the annealed straight lengths. This question is answered below in our reply to Mr. Marin's inquiry.

Mr. Schapiro has inquired into our method of measuring strains. The circumferential strains were measured by measuring the distances between the two dots of our photo grid which, as noted in the paper, were 0.01 in. apart. The radial or thickness strains were measured in only a few cases, see Table III or Fig. 12 for example. In these cases, the tube was cut open and the wall thickness was measured with pointed micrometers.

In reply to Mr. Marin, we did not attempt to interpret the fractures by using any of the theories of plasticity. In this respect, it might be pointed out that fractures occurred in what was really inhomogeneous material. Even though the conditions for fracture for annealed matter might have been attained at the neutral axis the surrounding work-hardened material would lend physical support to this material — for example, by delaying necking — and give higher bursting strength than would be anticipated from simple fracture studies under various stress states in homogeneous materials.

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[3] Head, Department of Engineering Mechanics, The Pennsylvania State University, University Park, Pa.

A SIMPLE ANALYSIS OF SMALL SPHERICAL PERMANENT INDENTATION IN METALS

By Henry M. Otte[1]

Synopsis

A simple phenomenological analysis is presented for calculating the size of small indentations produced in flat metal surfaces by a hard spherical indentor. The total depth of the permanent indentation is evaluated by finding the total displacement under load (elastic plus plastic) as a function of the load, and then subtracting the recoverable elastic displacement. The latter quantity may be obtained from Hertz's equations, while the former quantity can be calculated if certain assumptions are made about the stress-strain relationship of the indented material. In order to compare the theory with experiment, a stress-strain curve of the form $\sigma = b\epsilon^x$ has been postulated as a special case. An application of the theory is also made to the important practical problem of the relation between specific static load and hardness.

In the study of the macroscopic properties of metals, the measurement of small indentations has considerable importance. When permanent indentations are made under controlled conditions, the size of the indentation is used as a measure of hardness. Variously shaped indenters may be employed, but generally they are conical, pyramidal, or spherical. Of these the spherical is of greatest interest since its use yields the most information about the properties of the material.[2] Very small spherical indentations are of interest in the ball-bearing industry where indentations greater than a certain arbitrary size render the bearing useless for further service.

In this paper an attempt is made to consider in detail the elastic and plastic portions of the indentation process. During the initial stages of the process, the deformation will be completely elastic. With increasing load, plastic deformation sets in, and eventually the process will become mainly plastic. The case for which the indentation process is completely elastic or mainly plastic has been solved mathematically(**1, 2**),[3] but the intermediate case has not proved amenable to a complete, rigorous analysis. Unfortunately the intermediate stage is the one most commonly encountered in practice. In the present work the problem has been formulated in simple terms from which direct application to observations can be made. No attempt to obtain a rigorous mathematical analysis has been made.

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[1] Department of Mining and Metallurgical Engineering, University of Illinois, Urbana, Ill.

[2] Pyramidal or conical indentors give geometrically identical impressions whatever the depth of penetration, whereas spherical ones do not.

[3] The boldface numbers in parentheses refer to the list of references appended to this paper, see p. 1057.

PREVIOUS WORK

Since some space will be devoted to the application of the present analysis to the measurement of hardness, a few comments on this subject are appropriate here. Hardness may be defined in a number of ways. The most widely used definition—and adopted here—may be stated as follows: Hardness is the number obtained when the applied load, W (in kg), is divided by the projected area or the actual area (in mm) of the permanent indentation. Using the projected area gives a value known as the Meyer hardness, whereas using the actual area gives the Brinell hardness. These hardness values are not independent of load for spherical indentors but have been found to increase with increasing load W (3). This result means essentially that W is not proportional to the area of the indentation. The deviation is not large, and Meyer (4) found that observations could be fitted by an expression of the form:

$$W = k(d_p)^n \qquad (1)$$

where k and n are constants and d_p is the chordal diameter of the permanent indentation. This expression has been subjected to considerable experimental verification (3), and it has been found that n lies generally between 2 and 2.6. Later an equation of this form will be derived, but one in which d (the chordal diameter of the indentation while the indentor is still immersed in the specimen and the load applied) replaces d_p. However, it has been found by Tabor (5) that, if the true stress (σ) *versus* true strain (ϵ) curve for the material is approximated by the equation:

$$\sigma = b\epsilon^x \qquad (2)$$

where b is a constant and x is the "work-hardening capacity" constant, then n and x can usually be related by the simple equation $n = 2 + x$ when the form given in Eq 1 is used. Tabor also confirmed that in the cases of mild steel and annealed copper the Meyer hardness was approximately three times the yield strength in tension when further work-hardening of the material did not occur on additional deformation. A material that does not work-harden is generally regarded as being fully plastic, and, from the theory of two-dimensional plastic flow, it can be predicted that for a flat punch indenting a plastic material the mean pressure (which has the same units as Meyer hardness) should be approximately three times the yield stress of the material (6). The three-dimensional analysis of this axially symmetrical problem in plasticity presents difficulties that have not yet been surmounted.

Bishop, Hill, and Mott (2), however, were able to calculate a certain applied pressure, p_s, which would cause the surface of a spherical hole, in an infinite block of ductile material capable of work-hardening, to enlarge indefinitely by plastic flow. Assuming a stress-strain relationship of the form $\sigma = \sigma_0 + M\epsilon$ (where σ_0 is the initial yield point and M is a constant), they were able to obtain an expression for p_s in terms of σ_0, M, and the ratio of the plastic region to that of the hole. If this ratio was large, the expression involved a rapidly converging series that could be cut off at the first term. The ratio itself could be readily calculated and was a constant for a given material since it depended only on ν, E, and σ_0. On substituting numerical values in the expression for p_s, Bishop, Hill, and Mott found for mild steel that $p_s \simeq 7\sigma_0$ and for cold-worked copper $p_s \simeq 5\sigma_0$. This result was considered to be representative of deep penetration by a sphere; it would involve large strains (of the order of several hundred per cent) and therefore appreciable work-hardening. For shallow penetration, no part of the material would be highly strained (more than 40 per cent or so), and the analysis that follows could then be applied.

CALCULATION OF THE SIZE OF THE PERMANENT INDENTATION

The present analysis takes into consideration an important effect that so far has received only limited attention in the literature, namely, the elastic recovery of the indentation. Elastic recovery takes place in all directions when the load and indentor are removed, but that which occurs in the direction of the depth of the hole can be measured far more readily than the elastic recovery of the chordal diameter. As a result, elastic recovery, particularly of the diameter, has generally been neglected when considering hardness measurements.

In this paper an estimate is made of the elastic recovery of the diameter, d, as well as a determination of the elastic recovery of the depth, δ. The size of the permanent indentation is then obtained by deducting this elastic recovery (which takes place on removing the load) from the calculated size of the total indentation. In order to obtain comparison with data found in the literature, simplifications were necessary in parts. The quantity calculated was the depth, δ_p, rather than the chordal diameter, d_p, of the permanent indentation; this approach appeared simpler. For a small spherical indentation (of curvature ρ), simple geometric considerations show that the two quantities are related by the approximate equation $\delta_p \simeq \frac{1}{8}\rho(d_p)^2$. The final equation obtained for the depth, δ_p, of the permanent indentation had the following form:

$$\delta_p = AW^{2/(2+x)} - BW^{2/3} + \omega_c \quad \text{.....} (3)$$

where A, B, and ω_c are constants capable of evaluation. The first quantity on the right-hand side of the equation represents the total displacement under the applied load W; the second quantity represents the elastic recovery on removing the load and indentor; the third quantity, ω_c, may be interpreted as the elastic displacement of the circle of contact below the level of the flat specimen.

An expression of the form given in Eq 3 is valid for materials whose hardness lies between 590 and 800 DPH when loads up to 3000 kg are applied with a 10-mm diameter ball and may also be valid for softer materials when lighter loads are used.

Elastic Recovery of the Total Indentation:

In deriving the quantity:

$$BW^{2/3} = \omega_2 \quad \text{............} (4)$$

the starting point is Hertz's solution to the problem of the elastic contact of two bodies (1). For the special case of a ball (body 1) of curvature ρ_1 in elastic contact with a surface (body 2) of curvature ρ_2 under a load W, Hertz's calculations showed that the total approach of points not in the elastically distorted regions was:

$$\omega_1 + \omega_2 = 3W\vartheta/16a \quad \text{........} (5)$$

where:

$\vartheta = \vartheta_1 + \vartheta_2$,
$\vartheta_1 = 4(1 - \nu_1^2)/E_1$,
$\vartheta_2 = 4(1 - \nu_2^2)/E_2$,
ν = Poisson's ratio,
E = Young's modulus, and
a = the radius of the circle of contact =

$$[3W\vartheta/16(\rho_1 - \rho_2)]^{1/3} \quad \text{........} (6)$$

For a ball indenting a specimen, the elastic displacement of interest is that which occurs in the specimen on removing the load and indenter. By rearranging the above equations, this displacement is found to be:

$$\omega_2 = [(3/16)^{2/3}\vartheta_2/\vartheta^{1/3}](\rho_1 - \rho_2)^{1/3}W^{2/3} \quad \text{..} (7)$$

Initially, when the surface of the specimen is perfectly flat, $\rho_2 = 0$, and Eq 7 becomes:

$$\omega_2 = [\text{const.}]\rho_1^{1/3}W^{2/3} \qquad (7a)$$

As indentation proceeds and permanent deformation occurs, ρ_2 will assume finite values. Thus, strictly, ρ_2 will be a function of W. However, to retain sufficient simplicity, it will be assumed that the variation of ρ_2 may be neglected for the present purpose. The assumption is justified as long as $\rho_2 \ll \rho_1$.[4] Equation 7 may then be written as:

$$\omega_2 = BW^{2/3} \qquad (4)$$

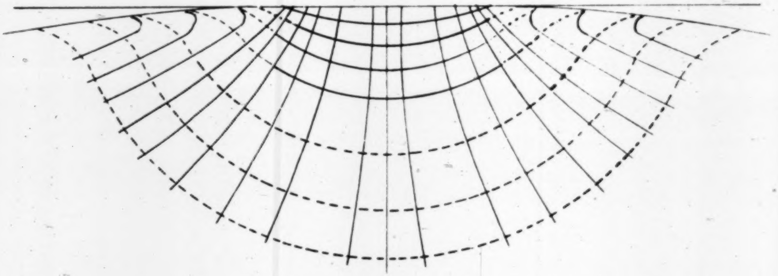

FIG. 1.—Lines of Principal Stress in an Elastically Deformed Body (**10**).

TABLE I.—VALUES FOR THE CONSTANT B, IN EQ 4 FOR THE ELASTIC RECOVERY OF AN INDENTATION, FOR METALS OF VARIOUS YOUNG'S MODULUS, E_2.

$E_1 = 6 \times 10^4$ kg per sq mm; $\vartheta_1 = 0.6 \times 10^{-4}$ sq mm per kg; $R = 5$ mm $= 1/\rho_1$.

E_2, kg per sq mm	ϑ_2, sq mm per kg	$B = [(3/16)^2\vartheta_2^3\vartheta^{-1}\rho_1]^{1/3}$, mm per kg$^{2/3}$
2×10^4	1.8×10^{-4}	5.547×10^{-4}
2.4	1.5	4.834
3	1.2	4.071

Table I gives values of B for a range of E_2. In calculating B, the value of E_1 for tungsten carbide has been taken as 6×10^4 kg per sq mm, and also $\nu_1^2 = 0.1 = \nu_2^2$.

The above considerations on the elastic recovery of the indentation are independent of the amount of prior plastic deformation recived by the material. This point is important since Eq 4 will be used to calculate the elastic recovery after various amounts of plastic deformation. Also, in the section on Size of the Total Indentation, use will be made of the elastic stress distribution when considering plastic flow around the indentation. That the same elastic stress distribution seems to be valid throughout a considerable range of plastic strain is indicated by the work of Mesmer (**7**). It also follows from the observation that generally the elastic constants are not affected by plastic deformation (**6, 8, 9**) and may therefore retain the same values (as long as the instantaneous shape of the element is always used to define them) throughout the range of deformations considered. Thus the original shape of the element is recovered on reloading to the initial state of stress. The stress distribution due to elastic deformation will therefore not depend on the amount of prior plastic deformation of the material.

The stress distribution in the case under consideration is reproduced in Fig. 1. The lines of principal stress, which have been deduced from Hertz's equations, are accurate only for the case where the pressure surface can be considered as vanishingly small compared with the surface of the ball. When this no longer applies, the solutions are only approximate. Furthermore, Hertz's theory is correct only for a surface that is plane in the deformed state. When passing from a plane to a spherical surface, the change in the stress distribution can still, however, be estimated qualitatively by means of Hertz's equations.

---

[4] Series expansion of $(\rho_1 - \rho_2)^{1/3}$ shows that for a second approximation the additional term $(1/3)\ \rho_1^{-2/3}\rho_2$ has to be considered. For this term to cause an error of less than 5 per cent, one must have $\rho_2 < 0.15\rho_1$ (or $R_2 > 6.7R_1$).

The maximum shear stress as calculated from Hertz's theory is found to be at a distance of about 0.5a below the center of contact and has a value of

$$\left.\begin{aligned} 0.945\,P_m \\ \text{with } P_m = W/\pi a^2 \end{aligned}\right\} \quad (8)$$

P_m has the units of a stress or pressure. The shearing stress along the periphery of the circle of contact is approximately 0.4P_m, and at the center of contact it is about 0.3P_m (**11**).

Throughout most of the calculations that follow, the elastic distortion of the ball indenter will be neglected. The reason for this is given by the following considerations. At first the area of contact between the ball and specimen is very small, and only local elastic distortion occurs. The surface of contact will have a certain curvature, ρ, given by Hertz's equation:

$$\rho = (\vartheta_2/\vartheta)\rho_1 + (\vartheta_1/\vartheta)\rho_2 \quad (9)$$

This equation shows that for a 5-mm radius ball ($1/\rho_1 = 5$) of tungsten carbide ($\vartheta_1 = 0.6 \times 10^{-4}$ sq mm per kg) indented into a flat ($1/\rho_2 = 0$) steel plate ($\vartheta_1 = 1.2 \times 10^{-4}$ sq mm per kg, say) the indentation radius of the ball has a maximum value of 7.5 mm and not 5 mm. This is the result of a purely elastic deformation occurring when contact is first made between the ball and the specimen. As indentation proceeds, however, the specimen yields plastically and the area of contact increases. The applied load is then distributed over an increasingly larger area, and the elastic distortion of the ball becomes progressively less. This distortion may be calculated from the following expression given by O'Neill (**12**):

$$\delta(1/\rho_1) = 0.14875[2W(1 + \nu_1)/\pi E_1]\rho_1 \quad (10)$$

For a 5-mm radius carbide ball and a load $W = 3000$ kg, $\delta(1/\rho_1) = 0.0012$ mm; this is a change of 0.24 per cent in the radius of the ball and can be neglected in the present case. The calculation assumes that the ball indenter is perfectly elastic with a yield strength greater than the ultimate strength of the specimen. It is thus valid for the greater part of the analysis that follows.

Size of the Total Indentation:

The calculation of the total indentation can now be considered. It involves using the known elastic stress distribution (Fig. 1) to estimate the stress and strain which just allows the ball indenter to increase its depth of penetration by a small amount when the applied load is increased slightly. The following expression for the depth, δ, as a function of the applied load, W, is obtained:

$$\delta = g(W) \quad (11)$$

The function $g(W)$ depends on the choice of an equation to represent the complete true stress *versus* true strain (σ-ϵ) curve. In order to obtain a more detailed insight into the form of Eq 11, it is necessary to analyze in some way the initiation and development of plastic flow during the process of indentation and also to consider a means of representing the strains involved.

The following relations will now be obtained for the stress σ and the strain ϵ:

$$\sigma = 0.945W/\pi a^2 \quad (12)$$

$$\epsilon = 2\beta\delta/a = \beta\rho a \quad (13)$$

where β is a constant.

The arguments leading to Eq 12 are as follows. Since initially the indentation process is elastic, Hertz's equations are applicable. As the load on the indenter is increased, plastic flow commences in certain regions. The region in which it first occurs is determined by the criterion of plastic yielding. Two criteria exist (13), but in the present case they both reduce to the same condition. The maximum shearing stress (or Guest-Mohr or Tresca-Saint Venant) criterion requires that the maximum shearing stress:

$$\tau_{\max} = \tfrac{1}{2}(\sigma_1 - \sigma_2) = \tfrac{1}{2}\sigma_0 \quad \ldots\ldots (14)$$

where σ_1 and σ_2 are the major and the minor principal stresses and σ_0 is the yield stress in tension. The maximum shear strain energy (or von Mises-Hencky) criterion postulates that yielding sets in when:

$$(\sigma_1 - \sigma_2)^2 + (\sigma_2 - \sigma_3)^2 + (\sigma_3 - \sigma_1)^2 = 2\sigma_0^2 \quad \ldots (15)$$

which, because of the symmetry along the z axis in the present problem ($\sigma_1 = \sigma_2$, $\sigma_2 = \sigma_3$), gives the same condition as before (Eq 14).

Now the greatest value of the shear stress around an indentation involving only elastic distortion has already been given in Eq 8; therefore, plastic yielding will first occur when:

$$0.945W/\pi a^2 = \sigma_0 \quad \text{or} \quad P_m = 1.07\sigma_0 \quad \ldots (16)$$

This yielding occurs in a region about 0.5a below the center of contact and need not actually result in a permanent indentation being formed in the very early stages. The first appearance of a permanent indentation on removing the indenter will occur when the applied load, W, first exceeds some critical value, W_c. The amount of plastic flow as indentation proceeds extends until a state of full plasticity is reached around the indenter.

The region along the periphery of the circle of contact requires consideration here, as well as the region, at a depth of 0.5a, considered above to be the region where plastic flow initiates. Along the periphery Hertz's elastic stress field indicates that yielding will first occur when:

$$0.4P_m = \sigma_0 \quad \text{or} \quad P_m = 2.5\sigma_0 \quad \ldots\ldots (i)$$

The resulting permanent indentation would then have a radius approximately of size a. The other region at a depth of 0.5a will at this stage, near W_c, also have undergone plastic deformation with the result that:

$$0.945P_m > \sigma_0 \quad \text{or} \quad P_m > 1.07\sigma_0 \quad \ldots (ii)$$

If the material work hardens, then the value of σ_0 at a depth of 0.5a will have increased to a value σ such that:

$$0.945P_m = 0.945W/\pi a^2 = \sigma \quad \ldots\ldots (12)$$

The value of σ then corresponds to the instantaneous yield stress.

The formation of a permanent indentation is visualized as passing through three stages. Initially plastic flow occurs only at a depth of 0.5a below the bottom of the indentation. This region then increases in size with further indenting and is accompanied by plastic flow at the periphery. As indentation is continued, these two regions meet, and eventually all the material in the immediate vicinity of the indentation has plastically deformed. The plastically deformed regions are considered to be bounded at all times by the surfaces:

$$\sigma_0 = \sigma_z - \sigma_y = \sigma_z - \sigma_x = o_x - \sigma_y \quad \ldots (17)$$

If indentation has proceeded only as far as the stage where deformation has occurred mainly along the periphery and at the bottom of the indentation, then the two regions represented by Eqs i and ii will be separated by material that has been only elastically deformed. Thus the elastic recovery of the total indentation after the application and removal of loads just above W_c is somewhat complex, and a simple relation is not likely to exist between the diameter and the depth of the permanent indentation. The elastic recovery between the bottom of the indentation and the periphery will in these early stages be such that the permanent indentation will not be spherical but will have a maximum curvature at the bottom.

Of the two relations given above for the initiation of yielding, the relation in Eq ii is to be taken as the condition governing the total amount of displacement, whereas Eq i will be satisfied at the same time only if the rate of work-hardening has a special value. If the rate of work-hardening does not have this value, then the relation in Eq ii is assumed to be the one that must be satisfied first.

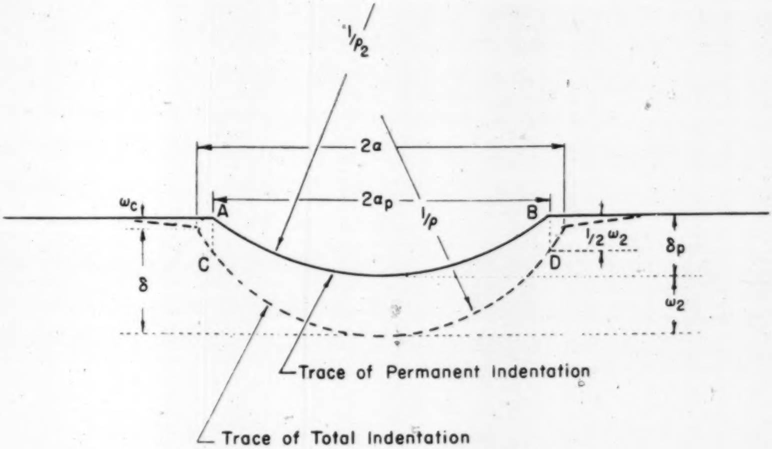

FIG. 2.—Explanation of Symbols Used in Text.

If the material work hardens, then the instantaneous yield stress, σ, will be a function of the amount of previous strain, ϵ, that is:

$$\sigma = f(\epsilon) \ldots\ldots\ldots\ldots\ldots (18)$$

Consequently it is necessary to have a relation between the size of the indentation and the strain at a depth of $0.5a$ where the shear strain is largest. Since Hertz's solution expresses the stress distribution inside a body in terms of the radius, a, of the contact area, the strain at any position will also be a function of $\left(\frac{x}{a}, \frac{y}{a}, \frac{z}{a}\right)$. For a small indentation of depth $\delta \simeq \frac{1}{2}\rho a^2$, the strain ϵ at a depth $0.5a$ below the center[5] of contact will be taken[6] proportional to δ/a, so that the strain at this point may be expressed approximately by the equation:

$$\epsilon = 2\beta\delta/a = \beta\rho a \ldots\ldots\ldots (13)$$

where ρ is the curvature of the indenter during indentation. At large loads, $1/\rho$ may be taken as R, the radius of the ball indenter. At low loads, near the critical load, $1/\rho$ will be slightly greater than R, as has already been pointed out. Thus ρ is actually slightly dependent on W.

Eliminating a between Eqs 12 and 13 yields:

$$\epsilon = \beta(0.945W/\pi\sigma)^{1/2}\rho \ldots\ldots\ldots (19)$$

which may be substituted in Eq 18 to give σ as an implicit function of the applied load, W. For special functions of $f(\epsilon)$, σ can be obtained explicitly thus:

$$\sigma = g'(W) \ldots\ldots\ldots (20)$$

The radius of contact may then be readily obtained in terms of W from Eq 12:

$$a^2 = (0.945/\pi)W/g'(W) \ldots\ldots\ldots (21)$$

and also the total depth of indentation:

$$\delta = \tfrac{1}{2}\rho a^2 = g(W) \ldots\ldots\ldots (11)$$

---

[5] Since the exact equation is $(\frac{1}{2})\ \rho a^2 = \delta - (\frac{1}{2})\ \rho\delta^2$, the error introduced by using the approximation is less than 5 per cent if $\delta < 0.1R$.

[6] See section on Comparison with Experimental Results and Discussion for a discussion of this assumption.

Permanent Indentation Remaining After Removing Load and Indenter:

Knowing the depth δ of the total indentation and the elastic recovery, ω_2, which occurs when the indenter is removed, the depth δ_p of the permanent indentation may now be easily obtained. From Fig. 2 it is readily seen that:

$$\delta_p = \delta - \omega_2 + \omega_c \qquad (22)$$

where ω_c is a small constant to be interpreted as an elastic displacement of the circle of contact below the level of the material. Its value is determined by the condition that the minimum value for δ_p is zero. This condition also yields a value for W_c, the critical load. Expressing δ_p in terms of W and differentiating gives:

$$0 = \frac{d(\delta_p)}{dW} = \frac{d}{dW} g(W) - \frac{2}{3} BW^{-1/3} \qquad (23)$$

whence W_c. The condition:

$$0 = g(W_c) - BW_c^{2/3} + \omega_c \qquad (24)$$

allows ω_c to be evaluated.

The diameter, $2a_p$, of the permanent indentation may be obtained by observing that, if the elastic recovery at the center of the indentation is ω_2, then the recovery will be approximately $\frac{1}{2}\omega_2$ at a radius of a_p if an extrapolated application of Hertz's theory is assumed. Therefore, with the aid of Fig. 2:

$$\tfrac{1}{2}\omega_2 + \omega_c = \tfrac{1}{2}\rho(a^2 - a_p^2) \qquad (25)$$

that is:

$$\begin{aligned} a_p^2 &= a^2 - (\omega_2 + 2\omega_c)R \\ &= 2(\delta - \tfrac{1}{2}\omega_2 + \omega_c)/\rho \qquad (26) \end{aligned}$$

The application of this equation to experimental results considered in a later section was fairly successful in spite of its limitations. Above $\delta = 0.1R$, the error resulting from the approximation $\delta \simeq \frac{1}{2}\rho a^2$ becomes more than 5 per cent, and large errors are thus involved in the use of Eq 26; errors also arise at low loads, near W_c, where ρ cannot be considered constant due to the elastic distortion of the ball indenter. Equation 26 gives $(a_p)^2 \neq 0$ at $W = W_c$ and thus needs a correction at these very low loads where the relationship between a_p and δ_p is complex.

Since the elastic recovery at the center of the cup-shaped indentation is more than it is at the periphery, the radius of curvature of the recovered indentation, when specified by a single value R', will be greater than R. Thus:

$$a_p^2 = 2R'\delta_p = 2R'(\delta - \omega_2 + \omega_c) \qquad (27)$$

Comparison with Eq 26 yields:

$$R' = [(\delta - \tfrac{1}{2}\omega_2)/(\delta - \omega_2)]R \longrightarrow R \quad \text{when } \delta \gg \omega_2 \qquad (28)$$

When $\omega_2 = \frac{1}{3}\delta$, $R' = 1.25\ R$, that is, the radius of curvature of the recovered indentation is 25 per cent larger than that of the indenter.

The Special Case When $\sigma = b\epsilon^x$:

In order to carry the analysis through more explicitly, a choice has to be made for $f(\epsilon)$ in Eq 18. No simple, completely satisfactory function exists. Though not always a good approximation, the relation:

$$\sigma = b\epsilon^x \qquad (2)$$

has received the widest application (**9**) and has also been capable of theoretical interpretation in special cases (**14**). Several other less widely applicable forms, also of an empirical nature, have been suggested, but only the above form, given by Eq 2, will be considered here. In this case Eq 20 becomes:

$$\sigma = [0.945b^{2/3}\beta^2\rho^2/\pi]^{x/(2+x)}W^{x/(2+x)} \qquad (20a)$$

and:

$$a^2 = [(0.945/\pi)^{2/(2+x)} \cdot (b^{1/x}\beta\rho)^{-2/(2+x)}]W^{2/(2+x)} \quad (21a)$$

When $x = 1$, that is, when $\sigma = b\epsilon$, which is Hooke's law with $E = b$, then:

$$a^2 = (0.945/\pi\rho E\beta)^{2/3}W^{2/3} \quad (29)$$

In other words, $a^2 \propto W^{2/3}$ in accordance with Hertz's elastic solution. Furthermore, it is numerically equal to his solution (with $\rho_2 = 0$) when:

$$\beta = 1.26/\pi(1 - \nu^2) = 0.42 \quad (30)$$

When $x = 0$, the initial conditions of yielding are merely obtained because the metal does not work harden.

If n is written for $2 + x$, $\rho = 2/D$ and $2a = d$; then:

$$W = ND^2(d/D)^n = kd^n \text{ (for constant } D) \quad (31)$$

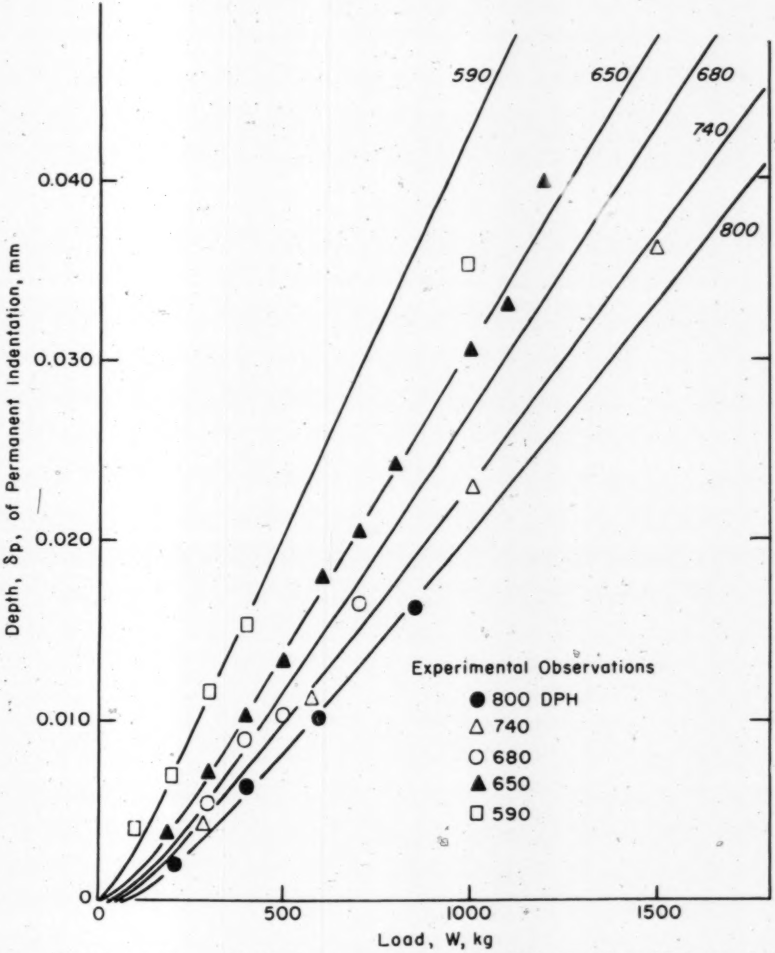

FIG. 3.—Calculated Curve (Solid Line) and Experimental Observations (Points) of the Depth of the Permanent Indentation for a Given Load in a Material of the Designated Hardness.

where $N = (\pi/3.78)b\beta^{n-2}$ = constant. Equation 31 is Meyer's formula if d is taken as the diameter of the permanent indentation instead of that of the total indentation.

The total depth of indentation is from Eq 11:

$$\delta = [\tfrac{1}{2}(0.945/\pi)^{2/(2+x)}\rho^{(2-x)/(2+x)} \cdot (b^{1/x}\beta)^{-2x/(2+x)}]W^{2/(2+x)} \quad (11a)$$

The term in brackets is essentially a constant (to be denoted by A) for a given value of x, so that:

$$\delta = AW^{2/(2+x)} \dots\dots\dots (11b)$$

TABLE II.—VALUES OF THE CONSTANTS IN EQ 21 WHICH GIVE THE BEST AGREEMENT WITH EXPERIMENTAL OBSERVATIONS FOR DEPTH OF PERMANENT INDENTATION.

Vickers Hardness Number	$\frac{2}{2+x}$	x	A	B	ω_c, mm	W_c, kg
800	0.85	0.353	0.000192	0.00049	0.0013	44.1
740	0.85	0.353	0.000200	0.00049	0.0011	35.3
680	0.86	0.326	0.000195	0.00048	0.0010	28.6
650	0.86	0.326	0.000200	0.00046	0.0008	20.0
590	0.87	0.300	0.000197	0.00038	0.0003	6.9

Below the yield point (where $x = 1$) Eq 11b reduces again to Hertz's solution for the elastic approach of two bodies, namely $\delta = AW^{2/3}$.

For a given value of x, the depth of the permanent indentation is, by Eq 22:

$$\delta_p = AW^{2/(2+x)} - BW^{2/3} + \omega_c \dots (3)$$

where A and B are constants capable of evaluation.

The radius of the permanent indentation is given by:

$$a_p^2 = 2R(AW^{2/(2+x)} - \tfrac{1}{2}BW^{2/3} + \omega_c) \dots (26a)$$

which is valid as long as R is constant.

The expression for the critical load, as deduced from Eq 23, becomes:

$$\begin{aligned} W_c &= [(2+x)B/3A]^{3(2+x)/2(1-x)} \\ &= [(2\{2+x\}/3)^{3(2+x)/2} \\ &\quad \cdot (3/16)^{(2+x)}(\pi/0.945)^3 \\ &\quad \cdot \vartheta_2^{3x}\vartheta^{2(1-x)}(b^{1/x}\beta)^{3x}]^{1/(1-x)}R^2 \end{aligned} \dots (32)$$

which, when $x = 1$, does not give a value for the critical load, and when $x = 0$, gives:

$$W_c = (4/3)^3(3/16)^2(\pi/0.945)^3\vartheta^2b^3R^2 \dots (32a)$$

COMPARISON WITH EXPERIMENTAL RESULTS AND DISCUSSION

The equation $\sigma = b\epsilon^x$ generally fits the observed stress-strain curve only over a limited range of stress or strain. Near the elastic limit, the value of x is not constant but approaches a limiting value of 1, which corresponds to pure elastic distortion. Nevertheless, a constant value of x may generally be found for the greater part of the stress-strain curve. With this in mind, the equations for the size of the indentation derived in the previous section for the special case, were applied to the published data of Yeo and Ko (**15**). These data on the variation with load of the depth of total and permanent indentation were obtained by pressing a sphere (10-mm diameter) of tungsten carbide into blocks of eutectoid plain carbon steel water-quenched from 800 C and tempered to various hardness levels between 590 and 800 DPH. The experimental results are plotted in Fig. 3, which also shows the curves obtained from the theory when the values for A, B, and x given in Table II are used. These values could not be determined with any high degree of precision and may be subject to as much as ±10 per cent error, though this is probably an overestimate.

TABLE III.—COMPARISON OF OBSERVED AND CALCULATED BRINELL HARDNESS NUMBER.

Vickers Hardness Number	Brinell Hardness Number[a] (3000-kg load)	d $(=2a_p)^b$ (at 3000-kg load)	Calculated Brinell Hardness Number
800	722	2.224	762
740	684	2.286	722
680	638	2.382	665
650	611	2.437	633
590	554	2.603	555

[a] From conversion tables in ASTM Standard Hardness Conversion Tables for Steel (E 48 – 47), 1955 Book of ASTM Standards, Part 1, p. 1657.

[b] Calculated from Eq 26*a*, using values in Table II.

Assuming the correctness of the choice for A, B, and x, the Brinell hardness may be evaluated by calculating a_p from Eq 26*a* and substituting in the equation:

$$BHN = W/2\pi R(R - \sqrt{R^2 - a_p^2}) \quad (33)$$

The result of these calculations is given in Table III.

The maximum difference between the calculated and the observed values (as determined from conversion charts) for the Brinell hardness is about 5.3 per cent, and in the case of the 590 DPH steel, agreement is almost exact. Though this is very satisfying, caution must be exercised in drawing too strong a conclusion regarding the success of the present analysis from the closeness of this agreement.

The constant A in Eq 11*b* contains two undetermined quantities, b and β, which can be calculated from the observed value of A given in Table II. By assigning various values to β, corresponding values of b can be determined (see Table IV).

TABLE IV.—SUMMARY OF CALCULATIONS.

Vickers Hardness Number	$b\beta^x$	$\beta = 0.42$	$\beta = 0.20$	$\beta = 0.05$	BHN (Calculated) / YS$(\beta = 0.05)^a$
800 $(x = 0.353)$	834.0	$b = 1133$ $\sigma_{0.2\%} = 126$	1472 164	2401 268	2.843
740 $(x = 0.353)$	794.9	$b = 1080$ $\sigma_{0.2\%} = 120$	1403 156	2288 255	2.835
680 $(x = 0.326)$	719.5	$b = 954$ $\sigma_{0.2\%} = 106$	1215 136	1908 213	3.122
650 $(x = 0.326)$	698.6	$b = 927$ $\sigma_{0.2\%} = 103$	1180 132	1853 207	3.058
590 $(x = 0.300)$	626.5	$b = 812$ $\sigma_{0.2\%} = 91$	1013 101	1534 171	3.246

[a] YS (Yield Strength) = $\sigma_{0.2\%}$ = stress (in kg per sq mm) at a strain of 0.2 per cent.

Since the experimental stress-strain curves for these steels are not available, a choice for β cannot be made. Tabor (5), in his empirical analysis, observed a ratio of 0.2 between the true strain and the fraction a_p/R. This would approximately correspond to β; the values of b then obtained are given in Table IV. The reason for considering a choice of $\beta = 0.42$ is apparent from Eq 30 in the treatment of the special case. The third choice of $\beta = 0.05$ arises from an attempt to make the BHN $\simeq 3\sigma_0$ (when both are expressed in the same units), using as a measure of σ_0 the stress at a strain of 0.2 per cent. The maximum strain possible during indentation occurs when the ball indenter is immersed up to its equator, that is, when $a = R$ or $\epsilon = \beta$. For $\beta = 0.20$ the maximum strain possible would correspond to 20 per cent.

An interpretation of β may be found by considering the strain to be measured at any given instant by the ratio of the total depth of indentation, δ, taken as an increment of deformation, to an arbitrary "instantaneous length" taken as a multiple of a. At the center of contact, the shearing stress is $0.3P_m$, and it has this value again at a depth of $2a$. Thus, if $2a$ were to be taken as the "instantaneous length," it is readily seen that this would give $\beta = 0.25$.

In Table V are given the values of the radius of curvature of the permanent indentation at 3000 kg as calculated from Eq 27, using the constants given in Table II. The permanent indentation was assumed to be perfectly spherical, whereas experimental observations have shown (**15**) that this is not exactly true. The exact deviation has not been reported, but it is probably small.

TABLE V.—CALCULATED RADIUS R' OF THE PERMANENT INDENTATION PRODUCED BY A 3000-KG LOAD ON A 10-MM BALL.

Vickers Hardness Number	At 3000 kg		$R' = (a_p)^2/2\delta_p$, mm
	$(a_p)^2$	δ_p	
800	1.2366	0.0727	8.5
740	1.3068	0.0797	8.2
680	1.4177	0.0918_5	7.7
650	1.4850	0.1017	7.3
590	1.6940	0.1299	6.5

If it is assumed that a permanent indentation is formed simultaneously with the occurrence of the initial yielding given by Eq 12, then the critical load is:

$$W_c = (\pi/0.945)a^2Y$$

$$= (\pi/0.945)(3W_c\vartheta/16\rho_1)^{2/3}Y$$

and this, on rearranging, gives:

$$W_c = (3/16)^2(\pi/0.945)^3\vartheta^2R^2Y^3 \quad \text{....(34)}$$

For $x = 0$, the critical load, W_c, given by this relation is 2.37 times smaller than that given in Eq $32a$. When $x > 0$, this factor increases, reaching an infinite value when $x = 1$—that is, when no critical load exists.

The expression for W_c in the form given by Eq 34 was applied by Davies (**16**) to the indentation of a hardened steel ball into a specimen of the same material. In this case $\vartheta = 2\vartheta_2 = 2(1.856 \times 10^{-4})$ sq mm per kg assuming the values used by Davies—$E = 2 \times 10^4$ kg per sq mm and $\nu = 0.286$. For a ball diameter of 9.525 mm ($\frac{3}{8}$ in.) and a specimen whose test machine yield point is 106.6 kg per sq mm (69 tons per sq in.), $W_c = 4.89$ kg. The observed critical load lay between 6.33 and 7.18 kg, which corresponds with values of ϑ_2 between 2.11×10^{-4} and 2.25×10^{-4} sq mm per kg. These values are rather high when compared with those in Table I. Using Eq $32a$, which assumes $x = 0$, the corresponding values of ϑ_2 obtained are 1.37×10^{-4} to 1.46×10^{-4} sq mm per kg, giving a value for E_2 of about 2.5×10^4 kg per sq mm, which corresponds closely to the figures giving good agreement with the data of Yeo and Ko (**15**).

An expression for the depth, δ_p, of the permanent indentation has been deduced from dimensional analysis by Palmgren (**17**) and has the following form for a ball (diameter $D = 2/\rho_1$) pressed into a cup (of curvature ρ_2), both of the same material:

$$\delta_p = 1.25 \times 10^{-5}(W^2/D)(\rho_1 + \rho_2)^2 \quad \text{..(35)}$$

According to this equation, no critical load exists; this is consistent with Palmgren's view that no such load can be determined since, however carefully the surfaces are prepared, they will be covered with hills and valleys which are large compared with the atomic dimensions, so that the surfaces, when first placed in contact, will be supported on the tips of their asperities and these will be deformed by even the smallest loads.

Davies (**16**), however, as mentioned above, was able to determine a critical load with a hard steel ball for a number of steels ranging in hardness from 125 to 770 DPH. He used optical methods to detect the existence of a permanent indentation, which could be observed if its depth was greater than 0.0005 mm (of the order of one wavelength of light). Furthermore, Palmgren's equation predicts that $\delta_p \propto W^2$, whereas the data of Yeo and Ko (**15**), as well as the present analysis, indicate that $\delta_p \propto W$ and that at low loads δ_p tends to become $\propto W^{2/3}$. From the published work of Palmgren (**17**) and others (**18**), it would appear that the effect of very low loads had not been investigated.

AN APPLICATION OF THE PRESENT ANALYSIS: THE RELATION BETWEEN SPECIFIC STATIC LOAD AND HARDNESS

In practical cases (such as in ball-bearing manufacture), it often happens that the value of importance is not the critical load, but some other slightly larger and more readily measurable load which gives an arbitrarily small indentation (insufficient to render the surface useless for further service). From this point of view, Palmgren (**17**) defined a specific static load:

$$k_s = \frac{\text{applied load, } W}{(\text{indenter ball diameter, } D)^2} \quad \text{..(36)}$$

which corresponded to a permanent indentation depth $\delta_p = 10^{-4}\, D$. The value of k_s, for ball and cup contact, was given by:

$$k_s = W/D^2 = 2.8D/(\rho_1 - \rho_2)^2 \cdot \\ [2/D = \rho_1 > \rho_2] \quad \text{..(37)}$$

where ρ_1 and ρ_2 are the curvatures of the ball indenter and the indented surface, respectively.

The value of k_s was found to vary with the Brinell hardness, but the variation, determined experimentally by Palmgren, could not be deduced from his equations. The present analysis allows an approximate relation to be derived in the following manner. The expression for the depth, δ, of the total indentation may be written, from Eq 11*a*, as:

$$\delta/D = (0.945/\pi)^{2/(2+x)} \cdot \\ (2b^{1/x}\beta)^{-2x/(2+x)}(k_s)^{2/(2+x)} \quad \text{..(11c)}$$

whereas in terms of the permanent indentation depth, δ_p, and the elastic recovery, ω_2, after unloading, it can be expressed, according to Eq 22, as:

$$\frac{\delta}{D} = \frac{\delta_p}{D} + \frac{\omega_2}{D} - \frac{\omega_c}{D} \simeq \frac{\delta_p}{D} + \frac{\omega_2}{D} \quad \text{..(22b)}$$

After substituting for ω_2 from Eq 7*a*, writing $W/D^2 = k_s$ everywhere, and eliminating δ between Eqs 11*c* and 22*b*, one obtains:

$$k_s = (\pi/0.945)(2\beta)^x b[(\delta_p/D) \\ + 2(3/32)^{2/3} k_s^{2/3} (\vartheta_2/\vartheta^{1/3})]^{(2+x)/2} \quad \text{..(38)}$$

The value of b is related to the hardness through the equation:

$$b = 0.945(\sqrt{\pi}/2\beta)^x (D/\sqrt{W})^x \cdot \\ (W/\pi a^2)^{(2+x)/2} \quad \text{..(39)}$$

If the hardness is measured under standard conditions, say with a 10-mm ball and a load of 3000 kg, then:

$$b = 0.945\pi^{x/2}(2\beta)^{-x}(30)^{-x/2} P_m^{(2+x)/2} \quad \text{....(39a)}$$

Inserting this expression for b in Eq 38 for k_s, β cancels and on substituting numerical values for ϑ and ϑ_2, one can reduce Eq 38 to:

$$k_s = \pi(\pi/30)^{x/2}[(\delta_p/D) \\ + 0.0012 k_s^{2/3}]^{(2+x)/2} P_m^{(2+x)/2} \quad \text{..(38a)}$$

If δ_p/D is equated to zero, then k_s will be the static carrying capacity corresponding to the critical load W_c. Making this substitution gives:

$$k_s = \left\{ [\pi(\pi/30)^{x/2}]^{3/(1-x)} \right.$$

$$\left. \cdot [0.0012]^{3(2+x)/2(1-x)} \right\} P_m^{3(2+x)/2(1-x)} \quad \text{. . (40)}$$

For indentations of size $d/D < 0.4$, the error caused by taking the Brinell hardness $B = H_M$, the Meyer hardness, is less than 5 per cent, and since $H_M = (a_p/a)^2 P_m$, it follows, for ranges of W over which a_p/a is approximately constant, that $B = (\text{const.})\, P_m$, so that Eq 40 becomes for a given value of x:

$$k_s = (\text{const.}) B^q \quad \text{. . . . . (41)}$$

where:

$$q = \frac{3(2 + x)}{2(1 - x)} \quad \text{. . . . . (42)}$$

Equation 41 is still approximately valid if $(\delta_p/D) \ll 0.0012\, k_s^{2/3}$. When $(\delta_p/D) \gg 0.0012 k_s^{2/3}$, Eq 38*a* may be written:

$$k_s \simeq \pi(\pi/30)^{x/2}(\delta_p/D) P_m^{(2+x)/2} \quad \text{. . . (43)}$$

so that here:

$$q = (2 + x)/2 \quad \text{. . . . . (44)}$$

The values of q in the two cases given by Eqs 42 and 44 for a range in values of x are presented in Table VI. Equations 41 and 43 apply to materials of different hardness but with the same work-hardening capacity.

TABLE VI.—VALUES OF THE EXPONENT q IN THE EQUATION FOR THE STATIC CARRYING CAPACITY, k_s, WHEN x LIES BETWEEN 0 AND $\frac{1}{2}$.

x	$q = \frac{3(2+x)}{2(1-x)}$	$q = \frac{2+x}{2}$
0	3	1
$\frac{2}{7}$ (0.3)	4	1.14
$\frac{1}{2}$ (0.5)	7.5	1.25

If δ_p/D is of the same order of magnitude as $0.0012 k_s^{2/3}$, then the relation between k_s and B is no longer simple. The log-log plot will no longer be quite linear, but in the range of interest ($k_s = 0.1$ to 2.0) a straight line may often be drawn. Table VI shows that, for a series of hypothetical materials whose work-hardening capacities, x, equal zero, the slope will vary from 1 to 3, whereas for a series of materials of different hardnesses, but all having the same x, the slope will vary between different limits (from 1.25 to 7.5 for $x = \frac{1}{2}$) depending on the choice of δ_p/D. If, however, the materials of different hardnesses do not all have the same value of x, complications arise which may produce a linear log-log plot over a considerably larger range than would be anticipated; the slope may also be affected. Palmgren, in a particular case quoted by Allan (**19**), obtained, when taking the readings from three steels of Brinell hardness 187, 457, and 665, a value of $q = 4$. This falls in the middle of the range of values predicted.

CONCLUSION

When the size of the indentation produced by an extremely hard substance (such as tungsten carbide) in a softer material is small, the elastic recovery that occurs on removing the indenter may be appreciable. By evaluating the magnitude of the total indentation for a given load and the elastic recovery, the size of the permanent indentation remaining on removal of the load may be calculated. In the range in which these calculations are valid, the input data necessary are the constants b and x, if an equation of the type $\sigma = b\epsilon^x$ is assumed for the total stress-strain curve, and the elastic constants E and ν. The calculations involve a constant $\beta \simeq 0.2$; comparison can be made with experimental data when sufficiently complete.

Acknowledgment:

The greater part of this work was done while the author was with the Department of Physical Metallurgy, Birmingham University, England. The author wishes to thank British Timken Ltd. for a grant that made work on this subject possible. The many helpful suggestions and criticisms of R. W. Balluffi, as well as the critical comments of T. A. Read and M. Metzger, are greatly appreciated.

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SUMMARY OF PROCEEDINGS OF THE SYMPOSIUM ON METALLIC MATERIALS FOR SERVICE AT TEMPERATURES ABOVE 1600 F

The papers and discussions in the Symposium on Metallic Materials for Service at Temperatures Above 1600 F, with the exception of "Thermal Shock Testing of High-Temperature Metallic Materials," by T. A. Hunter, were presented at the Twenty-fourth and Twenty-seventh Sessions of the Fifty-eighth Annual Meeting of the American Society for Testing Materials held in Atlantic City, N. J., June 30, 1955. The paper by Mr. Hunter was presented at the Twenty-ninth Session but is included in this publication since it is pertinent to and rounds out the symposium. This symposium was sponsored by the ASTM-ASME Joint Committee on Effect of Temperature on the Properties of Metals.

Introduction—V. N. Krivobok
Some Sheet and Bucket Materials for Jet-Engine Application at 1600 F and Higher—J. P. Denny, L. P. Jahnke, E. S. Jones, and F. C. Robertshaw
Influence of Boron on Cast Cobalt-Base S-816 Alloy—W. E. Blatz, E. E. Reynolds, and W. W. Dyrkacz
Effect of Heat Treatment and Structure Upon Creep Properties of Nimonic Alloys Between 750 and 950 C—W. Betteridge and R. A. Smith
Stress-Rupture Properties of Inconel 700 and Correlation on the Basis of Several Time-Temperature Parameters—S. S. Manson and G. Succop
Chromium-Nickel Alloys for High-Temperature Application—Albert G. Bucklin and Nicholas J. Grant
Effect of Rare Earth Additions on the High-Temperature Properties of a Cobalt-Base Alloy—J. E. Brach and J. R. Lane
Creep, Rupture, and Notch Sensitivity Properties of S-816 Alloy Up to 1650 F Under Fatigue and Stress—F. Vitovec and B. J. Lazan
Titanium-Carbide-Base Cermets for High-Temperature Service—K. Pfaffinger, H. Blumenthal and F. W. Glaser
Titanium-Carbide Products Produced by the Infiltration Technique—Leonard P. Skolnick and Claus G. Goetzel ,
High-Temperature Properties of Molybdenum-Rich Alloy Compositions Made by Powder Metallurgy Method—W. L. Bruckart and R. I. Jaffe
Tension and Torsion Tests on Nimonic Alloys at High Temperatures—E. D. Ward and W. G. Tallis
Thermal Fatigue Testing of Sheet Metal—H. E. Lardge
Thermal Shock Testing of High-Temperature Metallic Materials—Thomas A. Hunter
The Development of Zirconium-Rich Protective Coatings and Brazing Materials for Heat Resisting Alloys—A. Blainey

The papers and discussions were issued as *ASTM Special Technical Publication No. 174* entitled "Symposium on Metallic Materials for Service at Temperatures Above 1600 F."

SUMMARY OF PROCEEDINGS OF THE PANEL ON PYROMETRY

The Twenty-second Session of the Fifty-eighth Annual Meeting of the Society held in Atlantic City, N. J., on June 30, 1956, was devoted to a Panel Discussion on Pyrometric Practice in Elevated Temperature Testing. The session was sponsored by the Joint ASTM-ASME Committee on the Effect of Temperature on the Properties of Metal and was organized by the Test Methods Panel. The primary reason for holding this discussion and publishing it is the problem that has existed for some time with respect to test practices published by ASTM on elevated temperature tension tests, short-time tests, long-time tests and rupture tests.

The following formal discussions were presented:

Introduction—J. W. Freeman
Thermocouple Immersion Errors—J. M. Berry and D. L. Martin
Summary of Pyrometric Procedure Employed by One Company in Creep-Rupture Testing and an Analysis of Results Obtained—W. E. Leyda
Creep and Rupture Test Pyrometry—Charles R. Wilks
Closing Remarks—J. W. Freeman

The discussion was issued as *ASTM Special Technical Publication No. 178* entitled "Panel Discussion on Pyrometric Practices."

SUMMARY OF PROCEEDINGS OF THE SYMPOSIUM ON ATMOSPHERIC CORROSION ON NON-FERROUS METALS

The Symposium on Atmospheric Corrosion of Non-Ferrous Metals, sponsored by Committee B-3 on Corrosion of Non-Ferrous Metals and Alloys, was held at the Fourteenth and Seventeenth Sessions of the Fifty-eighth Annual Meeting of the Society in Atlantic City, N. J., on June 29, 1955. The authors of the papers comprising this symposium are combining reports of their own private work on the atmospheric corrosion of non-ferrous metals and that of Subcommittees VI on atmospheric corrosion and VIII Galvanic and Electrolytic Corrosion. It is their expectation that the information obtained in the 20-yr. exposure of various non-ferrous metals and alloys and the recently completed tests of galvanic couples, combined with the private work reported, will be useful in the proper selection of materials for atmospheric exposure.

The Symposium included the following papers:

Introduction—W. H. Finkelday
Resistance of Aluminum-Base Alloys to 20-Year Atmospheric Exposure—C. J. Walton and William King
Effect of 20-Year Marine Atmosphere Exposure on Some Aluminum Alloys—Fred M. Reinhart and George A. Ellinger
Effect of Natural Atmospheres on Copper—Copper: 20-Year Test—A. W. Tracy
The Atmospheric Corrosion of Copper—Results of 20-Year Tests—D. H. Thompson, A. W. Tracy and John R. Freeman, Jr.
Atmospheric Galvanic Corrosion of Dissimilar Metal Couples—H. O. Teeple
Galvanic Couple Corrosion Studies by Means of the Threaded Bolt and Wire Test—K. G. Compton and A. Mendizza
The Atmospheric Corrosion of Rolled Zinc—E. A. Anderson
The Use of Lead and Tin Outdoors—George E. Hiers and Elbert J. Minarcik
Atmospheric Corrosion Behavior of Some Nickel Alloys—H. R. Copson
Report of Subcommittee VI on Atmospheric Corrosion—Prepared by H. R. Copson

These papers, with discussions, were published as *ASTM Special Technical Publication No. 175* entitled, "Symposium on Atmospheric Corrosion of Non-Ferrous Metals."

SUMMARY OF PROCEEDINGS OF THE SYMPOSIUM ON IMPACT TESTING

The Symposium on Impact Testing was sponsored by the Subcommittee on Impact Testing of Committee E-1 on Methods of Testing in recognition of the need for development of more fundamental information with respect to the test. The papers and discussion included in this Symposium were presented at the First and Second Sessions of the Fifty-eighth Annual Meeting of The American Society for Testing Materials held in Atlantic City, N. J., on June 27, 1955.

The papers presented were:

Notched-Bar Testing—Theory and Practice—S. L. Hoyt
Transition Behavior in V-Notch Charpy Slow-Bend Tests—Carl E. Hartbower
Reproducibility of Charpy Impact Test—David E. Driscoll
Automatic Impact Testing From Room Temperature to −236 C—Thomas S. DeSisto
The Influence of Pendulum Flexibilities on Impact Energy Measurements—Joseph I. Bluhm
The Impact Tube: A New Experimental Technique for Applying Impulse Loads—George Gerard
Longitudinal Impact Tests of Long Bars with a Slingshot Machine—W. Ramberg and L. K. Irwin
Shock Tester for Shipping Containers—W. H. Cross and Max McWhirter
Properties of Concrete at High Rates of Loading—D. Watstein

Five papers were subsequently added in publishing the Symposium:

Effect of Specimen Width on the Notched Bar Impact Properties of Quenched-and-Tempered and Normalized Steels—R. S. Zeno
Effects of Manganese and Aluminum Contents on Transition Temperature of Normalized Nickel Steel—T. N. Armstrong and O. O. Miller
Low Temperature Transition on Normalized Carbon-Manganese Steel—T. N. Armstrong and W. L. Warner
Stress-Strain Relationships in Yarns Subjected to Rapid Impact Loading—Herbert F. Schiefer, Jack C. Smith, Franklin McCrackin, and W. K. Stone (Presented at the Symposium on Speed of Testing and published in both *STP Nos. 176 and 185*)
Shock Testing with the Rocket-Powered Pendulum—R. W. Hager

These papers, with discussion, were issued as *ASTM Special Technical Publication No. 176* entitled "Symposium on Impact Testing."

EFFECT OF DEPTH OF BEAM UPON THE MODULUS OF RUPTURE OF PLAIN CONCRETE*

By C. P. Lindner[1] and J. C. Sprague[2]

Synopsis

The load at failure of plain concrete beams does not vary as the conventionally visualized square of the depth, and the modulus of rupture of concrete varies inversely with depth. An attempt is made to rationalize this behavior and to point out some of its ramifications. The solution of the conventional formula, $S = Mc/I$, does not produce the true tensile breaking stress. An equation, termed the "rectibolic formula," is offered for measuring the tensile stress, the solution of which yields results that approach more closely the true breaking strength of concrete subjected to bending stresses. Measurements of the locations of the neutral axes and for the ratios of modulus of elasticity in compression to that in tension are given for various size beams. The results are consistent with the reduction in relative load-bearing capacity for increased depth of beam.

There has been increasing recognition of the fact that load at failure of concrete beams with dimensions having a constant relationship with each other does not vary as the square of the depth and that apparent flexural strength of concrete varies inversely with depth of beam (**1, 2, 3, 4, 5, 6, 7**),[3] but a comprehensive explanation of the reason has not been found in available published data on the subject. In an attempt to evaluate the strength of prototype pavement structures, concrete is molded into beams of constant depth which are then tested in flexure. Yet, when concrete of constant quality is cast into beams of various depths it exhibits variable apparent strengths under maximum bending loads that are related in an inverse manner to the depth of the beams.

Modulus of Rupture Test Data

Results of flexure tests conducted in the South Atlantic Division Laboratory, Corps of Engineers, on concrete beams ranging from 6 to 18 in. in depth are shown in Fig. 1 and Table I. Individual strengths are the average of two breaks for each beam. The coefficient of variation ranges from 10.1 per cent for the 6-in. beams to 6.7 per cent for the 18-in. beams. Square cross-section specimens with a constant length-depth ratio of three were cast from pavement concrete, using a medium grade 1-in. max. sized manufactured aggregate and were cured for 28 days in the standard manner.

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* Presented at the Fifty-eighth Annual Meeting of the Society, June 26-July 1, 1956.

[1] Chief Engineer, South Atlantic Div., Corps of Engineers, U. S. Army.

[2] Director, South Atlantic Div., Lab., Corps of Engineers, U. S. Army.

[3] The boldface numbers in parentheses refer to the list of references appended to this paper see p. 1079.

Since the length-depth ratio is constant, depth is the principal variant (**1, 4, 6**). Specimens were tested by the third-point method[4] normal to direction of placement of the concrete. In this connection, limited supplemental tests were made comparing third-point loading with center-point loading;[5] and comparing apparent strengths obtained by testing the beams in the same direction as cast, and in the opposite direction (top fibers in tension) with the strengths obtained from side testing. Tables II and III show the results of these supplemental tests. As was expected from literature on the subject, the center loading method with bending moment computed at the center of span showed flexural strengths that were appreciably higher than those obtained by the third-point method (**3, 4**). The effect of variable beam depth is in agreement with third-point loading results. The apparent strength, Table III, of beams was substantially the same, whether tested with side or top fibers in tension. However, when tested with the bottom fibers in tension a noticeable increase in strength was obtained. This was expected, following as it does natural effects of the tendency for water-gain in concrete (**8, 9**). At the bottom of Table III is shown the relative apparent strength of concrete cast in 9- and 6-in. beams. It is 90 per cent for side and top companion breaks, which is in substantial agreement with data shown in Table I. Those specimens which are companion for side and bottom tests show, respectively, 86 and 87 per cents for the ratio of the strengths of 9- to 6-in. beams. Of course the "86 per cent" and the "90 per cent" in column *3* are corresponding percentages, each being for companion specimens only. There is 1 per cent less drop in apparent strength between 6- and 9-in. beams when tested in direction of casting, as compared with side testing. This might be actual, or it might be due to experimental error—it was not explored further since the small difference is not significant for the purpose of this paper.

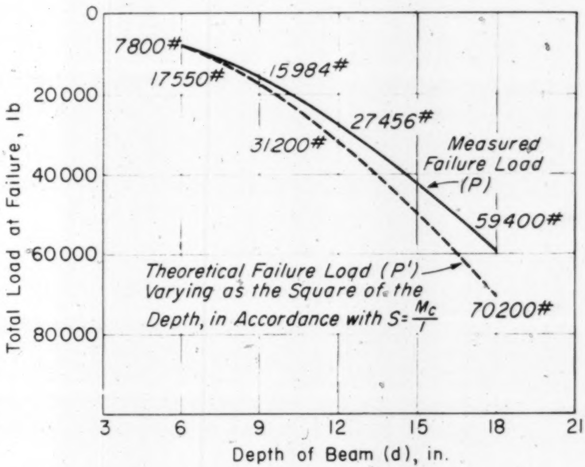

Fig. 1.—Loads Sustained by Beams of Various Depths.

The solid curve in Fig. 1 shows actual test failure loads *P* and the dashed

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[4] Standard Method of Test for Flexural Strength of Concrete (Using Simple Beam with Third-Point Loading) (C 78 – 49) Part 3, 1955 Book of ASTM Standards.

[5] Tentative Method of Test for Flexural Strength of Concrete (Using Simple Beam with Center-Point Loading) (C 293 – 52 T), Part 3, 1955 Book of ASTM Standards.

TABLE I.—COMPARISON OF MODULUS OF RUPTURE OF COMPANION CONCRETE BEAMS OF VARYING SIZE, PSI.

	6-in. Square Beams	9-in. Square Beams	12-in. Square Beams	18-in. Square Beams
	620	552	481	505
	595	549	558	...
	595	540	492	...
	550	513	478	466
	540	495	470	...
	555	523	498	...
	535	495	...	...
	...	542	...	...
	...	487	...	...
	655	595	579	565
	648	595	577	545
	682	600	640	...
	...	625	...	...
	...	600	...	...
	798	717	708	660
	805	703	670	...
	735	699	707	...
	...	722	...	...
	665	615	578	556
	670	550	570	570
	685	615	573	...
	...	655	...	...
	...	637	...	...
	718	595	575	535
Average (nearest 5 psi)	650	590	570	550
Average Load, P, lb	7800	15 984	27 456	59 400
	710	607	563	...
	656	605	530	...
	602	582	535	510
	611	...	498	...
	680	609	600	575
	417*	...	611*	...
	565*	...	613*	...
	680	581	623	...
	648	...	548	...
	609	572	596	...
	675	631	621	580
	660	585	636	...
Average (nearest 5 psi)	655	595	575	555
	625	...	...	515
	670	...	...	560
	655	588	570	...
	625	...	550	...
	660	...	575	...
	645	575	575	...
Average (nearest 5 psi)	645	580	565	540

* Erratic results not included in averages.

curve, theoretical maximum loads P which the concrete beams of varying depth should support as defined by conventional concept, for beams of the relative dimensions of those used, of load at failure varying as the square of the depth and assuming the failure stress in each beam to be the same as that obtained from the 6-in. beam tests. Data in Table I show the relative apparent flexural strengths (hereafter referred to as modulus of rupture) of the concrete as computed for the various sized beams from the actual loads at failure by conventional $S = Mc/I = Pl/bd^2$. The change in apparent strength based on standard 6-in. beams progressively reduced to 0.85 for the 18-in. beam. The per cent of theoretical load at which each beam actually failed coincides for each depth with the per cent apparent flexural strength for each size beam, with reference to the standard 6-in. specimen.

Although the apparent unit strength of concrete test specimens varies inversely with size both in compression and flexure, the latter is relatively more significant. No calculated value of stress, strength, or deformations can be regarded as exact. The formulas used are based upon certain assumptions as to properties of the material, regularity of form, and boundary conditions that are only approximately true, and they are derived by mathematical procedures that frequently involve other approximations. A disadvantage of using an allegedly "precise" formula is the possibility of being misled into thinking that the result it yields corresponds to a real condition.

Limitations of Conventional Formula:

The general modulus of rupture formula, $S = Mc/I$, is based upon the assumption that moduli of elasticity in compression and tension are equal and that the stress-strain diagram is a straight line. Assuming the stress-strain relationship to be a straight line below the elastic limit, it is valid only when stresses produced are within the elastic limit, beyond which deflection increases more rapidly than load. Since this expression is no longer valid after the elastic limit of the material has been exceeded, it cannot be applied to determine actual conditions after that point has been passed. For purposes of comparison of brittle materials, however, it has been convenient to determine the value of *S* from this formula with *M*, the moment, just preceding rupture. Modulus of rupture, which lies between ultimate tensile and ulimate compressive strength, and does not express actual stress in the extreme beam fiber, is useful primarily for the purpose of showing relative strengths of specimens of the same shape and size. In the conventional formula the tensile and compressive stresses in a beam are considered proportional to the distances of the extreme fibers from the neutral axis, and a single modulus of elasticity is assumed to apply to both tension and compression. For a beam composed of identical material throughout and of uniform section this places the neutral axis at the center of the beam. Actually the neutral axis must be positioned in accordance with the condition that the forces distributed over any cross-section must result in a resisting couple. In the derivations that follow strain during bending is assumed as substantially proportional to the distance from the neutral axis. In the discussion an attempt is made to rationalize the apparent facts developed by tests. There is no known way to prove them mathematically, but certain hypotheses may serve to make them conformable to principles satisfactory to reason.

TABLE II.—MODULUS OF RUPTURE OF VARIABLE SIZED BEAMS, CENTER VERSUS THIRD-POINT LOADING CONDITIONS.

Third-Point Loading		Center-Point Loading	
6-in. Beam, psi	9-in. Beam, psi	6-in. Beam, psi	9-in. Beam, psi
1	*2*	*3*	*4*
708	600	783	685
704	614	791	681
712	607	787	683
675	631	755	709
685	580	757	676
580	586	725	678
600	570	735	655
590	584	...	665
660	631	811	709
699	573	704	629
606	592	609	725
587	587	725	671
592	567	636	648
590	...	...	...
745	590	880	650
665	610	750	700
715	620	730	700
Average (nearest 5 psi) 655	595	745	680

Average ratio of 9:6-in. beam = columns *2* ÷ *1* and *4* ÷ *3* = 0.91.

Average ratio of center to third-point loading = columns *3* + *4* ÷ columns *1* + *2* = 1.14.

Stress Diagrams and Effect of Differential Moduli of Elasticity Thereon

Differential Moduli of Elasticity:

The ultimate moduli of elasticity of concrete in simple tension and in compression have generally been considered to be the same. Since the shape of the stress diagram and the location of the neutral axis will change when the elastic limit in tension is exceeded, it seems obvious that the moduli of elasticity in the tension and compression fibers of a concrete beam will be unequal when failure load is approached. The ratio of compressive to tensile strength of concrete tested by conventional means is of the order of 12 to 1, and conventional modulus of rupture is about 1.75 times the magnitude of simple tension. Preliminary data obtained in the laboratory indicated that the ratio of compressive secant modulus of elasticity E_c of concrete stressed to 10 per cent of ultimate 28-day strength to conventional tensile secant modulus of elasticity E_t of concrete stressed to approximately 90 per cent of ultimate strength was of the order of 1.37; extrapolated data from other sources (**10**) of moduli of elasticity determinations on concrete in compression (at about 8 per cent ultimate strength) and tension (at close to ultimate strength) indicate that the secant modulus ratio E_c/E_t is of the order of 1.5. In subsequent development of equations for determining tensile and compressive stresses for a concrete test beam subjected to failure load, the concept that $n = E_c/E_t$ varies from unity is used. When $n \neq 1$, a shift in neutral axis is necessitated in order that the

TABLE III.—EFFECT OF DIRECTION OF APPLICATION OF LOAD, WITH RESPECT TO DIRECTION OF CASTING VARIABLE SIZED BEAMS, UPON THE MODULUS OF RUPTURE (S) OF CONCRETE.

	Beams Tested in Same Direction as Cast (↓)		Beams Tested Normal to Direction as Cast (→)	Beams Tested in Opposite Direction as Cast (↑)	
	psi	Ratio ↓/→	psi	psi	Ratio ↑/→
	1	*2*	*3*	*4*	*5*
			6-IN. SQUARE CROSS-SECTION BEAMS		
	*		*	*	
	600	0.99	605	635	1.05
	520	1.03	505	505	1.00
	...	...	530	515	0.97
	650	1.03	633	...	...
	635	1.04	609	...	...
	...	...	625	625	1.00
Weighted Comparative Averages	$619^{(a)}$**	1.02+	$605^{(a)}$		
			$567^{(b)}$	$570^{(b)}$	1.00
			9-IN. SQUARE CROSS-SECTION BEAMS		
	*		*	*	
	508	1.06	481	490	1.02
	518	1.06	488	505	1.03
	...	...	492	492	1.00
	563	1.03	548	...	...
	...	...	580	555	0.96
	555	1.02	543	...	...
	...	...	572	545	0.95
Weighted Comparative Averages	$539^{(c)}$	1.04−	$519^{(c)}$		
			$510^{(d)}$	$513^{(d)}$	1.00
Relative, *S* 9:6 in. Beams	87% = (c ÷ a × 100)		86% = (c ÷ a × 100) 90% = (d ÷ b × 100)	90% = (d ÷ b × 100)	

* Individual average strength results represent an average of four specimens each. The individual averages on a given line are companion to each other for the conditions of loading.

** Letters a, b, etc. designate companion averages, based upon tests of companion specimens.

forces distributed over the cross-section will form a resisting couple. The term y, which is greater than $d/2$ when $n > 1$, is used to express the distance from the neutral axis to extreme fiber stressed in tension.

Shifting the neutral axis along the conventional rectilinear stress diagram results in inequality between the compressive force and the tensile force. In order to make this a couple it will be necessary either to shift the neutral axis back to the centroidal axis, or to change the compressive stress or the tensile stress in the extreme fibers. Since the neutral axis will shift toward the stronger side of a beam when the elastic limit in the weaker side is exceeded, if the tensile stress in the extreme fibers remains unchanged there must be an increase in the compressive stress with a concomitant increase in the load which the beam will support. If the compressive stress in the extreme fibers remains unchanged there must be a decrease in the tensile stress with a corresponding decrease in the load which the beam will support. Test results confirm that load at failure does not vary as the square of the depth and a different tensile stress diagram than that conventionally assumed is indicated. The exact shape of the diagram is not known, so different types of stress distributions have been studied in an attempt to get a clearer picture of the forces acting upon the beam. As the compressive side of the beam is stressed only to a small percentage of its utlimate strength, the conventional straight line stress-strain diagram on that side of the beam is assumed in the derivations that follow.

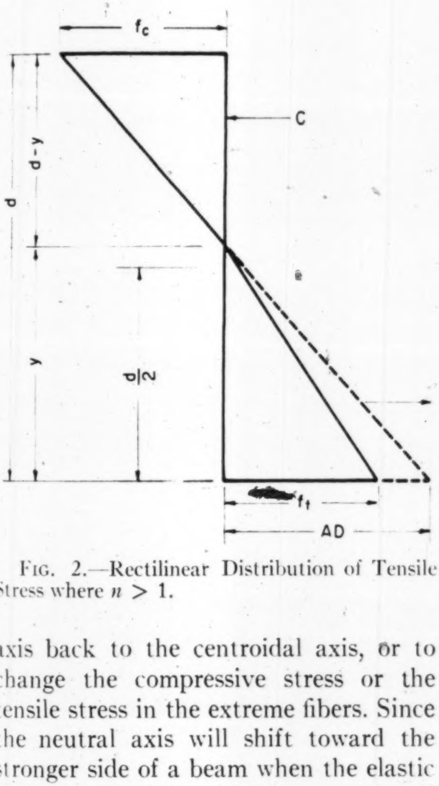

FIG. 2.—Rectilinear Distribution of Tensile Stress where $n > 1$.

Quasi Rectilinear Stress Diagram:

First, assume a rectilinear distribution of tensile stress where the secant modulus ratio $E_c/E_t > 1$. See Fig. 2. This is an abstract concept and is included only for purposes of illustration.

$$C = \frac{f_c}{2}(d - y) = T = \frac{f_t y}{2} \quad \ldots\ldots (1)$$

$$\frac{f_c}{f_t} = \frac{y}{d - y}$$

e_c = contraction in compression

e_t = elongation in tension

$$\frac{f_c}{f_t} = \frac{E_c e_c}{E_t e_t}$$

From the assumption that strain varies as a straight line from top to bottom of the beam:

$$\frac{e_c}{e_t} = \frac{d - y}{y}$$

$$\frac{f_c}{f_t} = \frac{E_c(d - y)}{E_t y}$$

$$\frac{E_c}{E_t} = n$$

$$\frac{n(d - y)}{y} = \frac{y}{d - y}$$

$$y^2\left(1 - \frac{1}{n}\right) - 2\,dy + d^2 = 0 \quad \ldots\ldots (2)$$

Now assume values for f_t in terms of AD, recognizing that n is the reciprocal of f_t/AD, and obtain the position of the neutral axis for which $C = T$. Corresponding values for y and n are as follows:

f_t	y	n (Reciprocal of f_t/AD)
$0.6AD$	$0.563d$	1.67
$0.7AD$	$0.544d$	1.43
$0.8AD$	$0.528d$	1.25
$0.9AD$	$0.513d$	1.11
$1.0AD$	$0.500d$	1.00

These values indicate that as the ratio n increases there will be a shift of the neutral axis to the compressive or stronger side of the beam. The greater the shift to the stronger side the smaller becomes the ratio f_t/AD.

Parabolic Stress Diagram.—A parabolic distribution of tensile stress where $n > 1$ is now assumed. See Fig. 3.

$$C = \frac{f_c}{2}(d - y) = T = \frac{2f_ty}{3}$$

$$\frac{f_c}{f_t} = \frac{4/3y}{d - y} \quad \ldots\ldots\ldots\ldots (3)$$

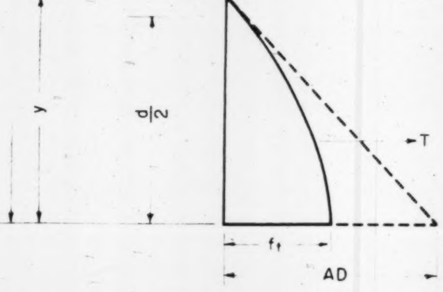

FIG. 3.—Parabolic Distribution of Tensile Stress ($n > 1$).

From the assumption that strain varies as a straight line from top to bottom of the beam:

$$\frac{e_c}{e_t} = \frac{d - y}{y}$$

$$\frac{f_c}{f_t} = \frac{E_c(d - y)}{E_ty}$$

$$\frac{n(d - y)}{y} = \frac{4/3y}{d - y}$$

$$y = \frac{d(1 \pm \sqrt{4/3n}}{1 - 4/3n} \quad \ldots\ldots\ldots (4)$$

Assume values for f_t in terms of AD and obtain the position of neutral axis for which $C = T$; resulting values for y and n are as follows:

f_t	y	n
$0.5AD$	$0.551d$	2.00
$0.6AD$	$0.528d$	1.67
$0.7AD$	$0.509d$	1.43
$0.75AD$	$0.500d$	1.33
$0.8AD$	$0.492d$	1.25

These values show the same trend as the rectilinear distribution, but the y values for the corresponding f_t values are appreciably smaller, indicating that if the stress distribution is parabolic the neutral axis would not shift as much since the fibers near the neutral axis help to carry the stress to a greater extent than in a rectilinear distribution. The tensile parabolic stress diagram is not tangent to the compressive linear diagram when f_t varies from 0.5 AD. It is also noted that if f_t exceeds 0.75 AD, y will become smaller than $d/2$. For this to occur, the initial modulus of elasticity would have to be greater in tension than in compression. Since this is not a real condition, it is likely that the stress distribution is not parabolic over the entire portion of the depth in tension.

Development of Rectibolic Formula

With this in view, a stress distribution was assumed that is rectilinear until some unknown stress intensity is reached, and then becomes parabolic, herein termed "rectibolic" stress distribution. The point at which the stress curve diverges from a straight line is designated herein the rectilinear limit. Figure 4 shows this graphically and utilizes the conventional assumption that the initial moduli of elasticity in tension and compression are essentially the same. The concrete in the beam has reached the rectilinear limit in tension at the line *RL*, and the stress in the area below exceeds the so-called rectilinear limit. The elastic limit in compression has not been reached, so that the compressive stress is considered proportional to the distance from the neutral axis.

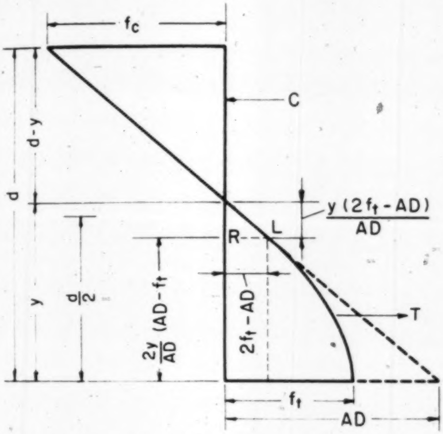

FIG. 4.—Linear-Parabolic ("Rectibolic") Distribution of Tensile Stress ($n > 1$).

$$C = \frac{f_c}{2}(d - y)$$

$$T = \frac{y(2f_t - AD)^2}{2AD} + \frac{2y(AD - f_t)(2f_t - AD)}{AD} + \frac{4y(AD - f_t)^2}{3AD}$$

$$T = \frac{y}{3AD}\left(4f_tAD - \frac{(AD)^2}{2} - 2f_t^2\right). \quad (5)$$

$$\frac{AD}{y} = \frac{f_c}{(d - y)}; \qquad AD = \frac{yf_c}{(d - y)}$$

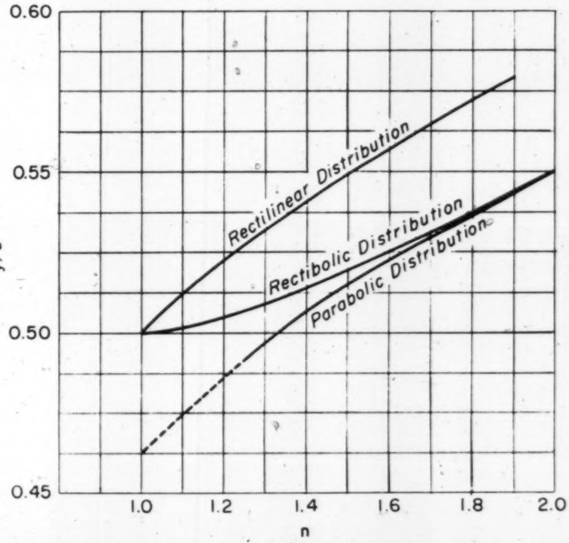

FIG. 5.—Interrelationship Between Parabolic, Rectilinear and Rectibolic Stress Distributions.

$$C = T \therefore \frac{f_c}{2}(d - y)$$

$$= \frac{(d-y)}{3f_c}\left(\frac{4yf_tf_c}{(d-y)} - \frac{y^2f_c^2}{2(d-y)^2} - 2f_t^2\right)$$

$$\frac{f_c}{f_t} = \frac{4\left(\frac{y}{d-y}\right) \pm \sqrt{12\left[\left(\frac{y}{d-y}\right)^2 - 1\right]}}{3 + \left(\frac{y}{d-y}\right)^2}$$

From the assumption that strain varies as a straight line from top to bottom of the beam:

$$\frac{e_c}{e_t} = \frac{d-y}{y}$$

$$\frac{f_c}{f_t} = \frac{E_c(d-y)}{E_ty}$$

$$\frac{\frac{4y}{d-y} \pm \sqrt{12\left[\left(\frac{y}{d-y}\right)^2 - 1\right]}}{3 + \left(\frac{y}{d-y}\right)^2} = \frac{n(d-y)}{y}$$

$$n = \frac{y}{d-y}\left[\frac{\frac{4y}{d-y} \pm \sqrt{12\left[\left(\frac{y}{d-y}\right)^2 - 1\right]}}{3 + \left(\frac{y}{d-y}\right)^2}\right] \dots (6)$$

Let $m = \frac{y}{d-y}$

$$n = m\left[\frac{4m \pm \sqrt{12(m^2-1)}}{3 + m^2}\right] \dots (7)$$

Assume values of f_t in terms of AD. The resulting values of n may be used in either Eqs. 6 or 7 to determine y.

Values obtained are as follows:

f_t	m	n	y
$0.50AD$	1.224	2.00	$0.551d$
$0.75AD$	1.045	1.33	$0.511d$
$1.00AD$	1.000	1.00	$0.500d$

It will be noticed that the value of y for $f_t = 0.5\ AD$ is the same as for the parabolic distribution, and for $f_t = AD$ it is the same as for the rectilinear distribution. This is shown clearly in Fig. 5.

In order to solve for stresses fitting the rectibolic concept of stress diagram it is necessary to establish the moment equation. On the tension side (Fig. 4) the total area was split into its subordinate geometric shapes, the moment for each being computed and the summation determined.

The appendix shows the derivation of the moment:

$$M = \frac{f_c(d-y)}{2}\left[2/3(d-y) + \frac{yf_t}{AD}\left(\frac{f_tAD + AD^2 - f_t^2}{4f_tAD - \frac{AD^2}{2} - 2f_t^2}\right)\right]$$

Solving for f_t:

$$f_c = \frac{d-y}{y}AD$$

$$M = \frac{(d-y)^2AD}{2y}\left[\frac{2(d-y)}{3} + \frac{2yf_t}{AD}\left(\frac{f_tAD + AD^2 - f_t^2}{8f_tAD - AD^2 - 4f_t^2}\right)\right]$$

$$\frac{f_t}{AD} = \frac{1}{n}; \qquad AD = nf_t$$

$$M = \frac{(d-y)^2nf_t}{y}\left[\frac{(d-y)}{3} + \frac{y}{n}\left(\frac{n + n^2 - 1}{8n - n^2 - 4}\right)\right] \dots (8)$$

$$f_t = \frac{My}{n(d-y)^2\left[\frac{(d-y)}{3} + \frac{y}{n}\left(\frac{n+n^2-1}{8n-n^2-4}\right)\right]} \quad (9)$$

The moment in the foregoing equation is the moment sustained by one unit of the width of the beam. So that M may represent the total moment on the beam section, M/b is substituted for M shown in the above equation. Then changing f_t to S_n, to conform to symbolism analogous to that used in the standard flexure formula, the rectibolic equation for tensile stress at rupture becomes:

$$S_n = \frac{My}{nb(d-y)^2\left[\frac{(d-y)}{3} + \frac{y}{n}\left(\frac{n+n^2-1}{8n-n^2-4}\right)\right]} \quad (10)$$

A conversion chart, Fig. 6, has been developed for simplifying the solution of the equation for beams subjected to third-point loading.

It has been pointed out that the value of n is the reciprocal of f_t/AD. Thus it becomes evident that for the same ratio of f_t/AD the type stress distribution *per se* has no effect on the value of n other than to indicate relative shift in the neutral axis. In view of uncertainty regarding the exact shape of the stress diagram, it is necessary to assume a type stress distribution for experimentally determined values of n in order to determine the stresses. The rectibolic stress distribution concept appears to offer a logical approach. Using rectibolic formulae, values of f_c and f_t were determined from actual test loads at failure for increments of shift in neutral axis for the various sized beams. These values, which are shown in Fig. 7, indicate the wide spread in compressive and tensile stress values that must obtain in order for a couple to be maintained as the neutral axis shifts. It will be noted from the graph that for any given position of neutral axis the stresses decrease with an increase in depth of beam. When expressed as a percentage of the stress in the 6-in. beam, there is the same percentage reduction in apparent stress as indicated by the stresses in Table I. Therefore, the decrease in modulus of rupture with depth must be attributed to causes other than the shift in neutral axis, unless it can be shown that the ratio of the shift to the beam depth varies with the depth of beam.

VARIABLE SHIFT IN NEUTRAL AXIS WITH CHANGES IN DEPTH OF BEAM

Laws of probability provide a basis for the hypothesis that when beams are subjected to bending stresses, E_t should tend to become smaller with an increase in the depth of beam and that E_c should remain substantially constant. These changes in moduli of elasticity would result in differential values for n for variations in depth of beam. This hypothesis involves the premise that as the size of concrete beams increase the probability of the presence of a larger and larger number of flaws increases (**5, 6**). If the strength of a beam is weakened by a flaw, then in effect the area which resists the applied load has been reduced slightly and consequently for the same magnitude of load the remaining fibers are stressed to an increased extent —that is, to an extent greater than would be indicated by a calculation utilizing the neat area of the beam, especially the tensile area. The total effect, of course, would be the summation of all flaws. This increase in stress in the fibers will cause an increase in strain for a given load but at failure of the specimen the

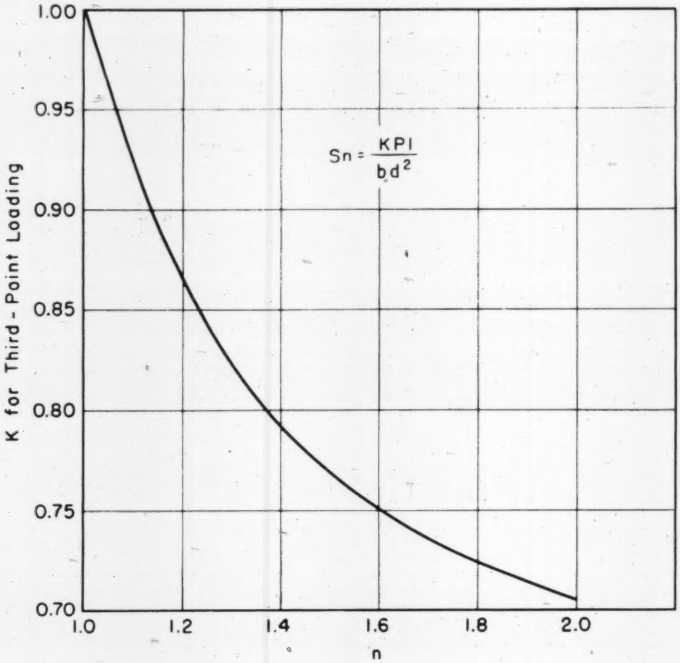

FIG. 6.—Factors for Converting Results from Standard Flexure Formula to those of Rectibolic Formula.

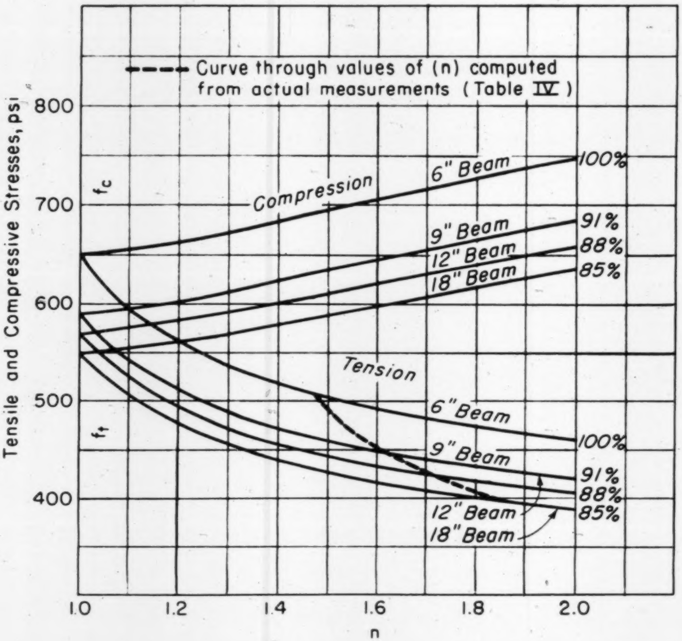

FIG. 7.—*n Versus* Stresses Computed by the Rectibolic Formula from Actual Loads at Failure.

tensile strain should be approximately the same value as if no flaw existed. Because of the greater probability of the occurrence of flaws as sections enlarged, deeper beams would resist a smaller proportionate load as depths increased to obtain the limiting strain. On the compressive side of the beam, the stress and strain should tend to decrease as the beam increased in depth since the load sustained would be proportionately less.

Test Procedures:

The direct measurement of induced stress or strain appeared to offer the only means by actual test for ascertaining the validity of this hypothesis. Since no positive means, which is insensitive to extraneous forces, has yet been developed for measuring internal compressive and tensile stresses in a small concrete specimen it seemed indicated that strain and the position of the neutral axis should be measured. This would permit *n* to be determined from the latter, and moduli of elasticity could be approximated by use of stresses calculated from the rectibolic formula.

Strain measurements were made with A-7, SR-4 strain gages mounted on the beams at appropriate locations, specifically at the top and bottom fibers and at closely spaced intervals on the sides between centroidal axes and extreme compressive fibers. The gages were connected with an SR-4 strain indicator by switching leads. The concrete was thoroughly dried throughout and maintained at a temperature of about 70 F in order to minimize volume change and to insure positive bond between the gages and the specimen. Ten gages were mounted on each specimen and readings were taken at increasing increments of loading until the beam had ruptured. The beam deflection was measured with Ames dials having a sensitivity of 0.0001 in., fastened to 2-in. angles which were pivoted to the concrete on each side of the beam at the intersection of the centroidal axis and extended vertical lines of the suport reactions. The contact point for each dial at the center of the span was supported by a band fastened rigidly around the perimeter of the beam.

When subjected to sustained loading, concrete may be expected to deform elastically by a definite amount and, in addition, to deform inelastically by an amount which increases with time. This inelastic deformation has been variously termed "plastic flow," "time yield," "creep," and "plastic strain." The two types of deformation of concrete under stress are so intimately related it is difficult to determine where one leaves off and the other begins. For this reason this stress-strain relationship has frequently been termed "sustained" modulus of elasticity. Normally, of course, the time-yield characteristic is considered significant primarily because of its contribution to favorable redistribution of stresses in a concrete structure; for this reason there are voluminous data on plastic flow over long periods of time. The time element of interest in connection with this test program, however, was a matter of seconds and minutes while the concrete was under bending load, and there is a paucity of data on the inelastic behavior of concrete under these conditions. Tests on concrete subjected to compressive stress have indicated that plastic flow in compression constitutes an appreciable part of total deformation for maximum loading for periods as short as one minute (11).

Test Results:

During the load-deformation readings on about half the specimens, each load increment normally requiring approximately 45 sec, double readings were recorded; these double readings required a total elapsed time at each load of approximately 2 min. With few exceptions, the double sets of readings checked each other within about 5 microinches per in. Since it did not seem pertinent, for the purpose of this investigation, that a distinction be made between elastic and inelastic deformation, no serious efforts were directed toward making such a distinction. If, however, there was an indeterminate significant residual deformation which is not being taken into consideraion it would not affect the validity of the end result, since it has been estblished by plastic flow tests in compression (**12**) that larger concrete masses show relatively less plastic flow than do smaller masses. This being the case, it may be seen by referring to Fig. 8 that the compressive strain curves would tend to draw closer together and that the tensile strain curves would tend to spread further apart.

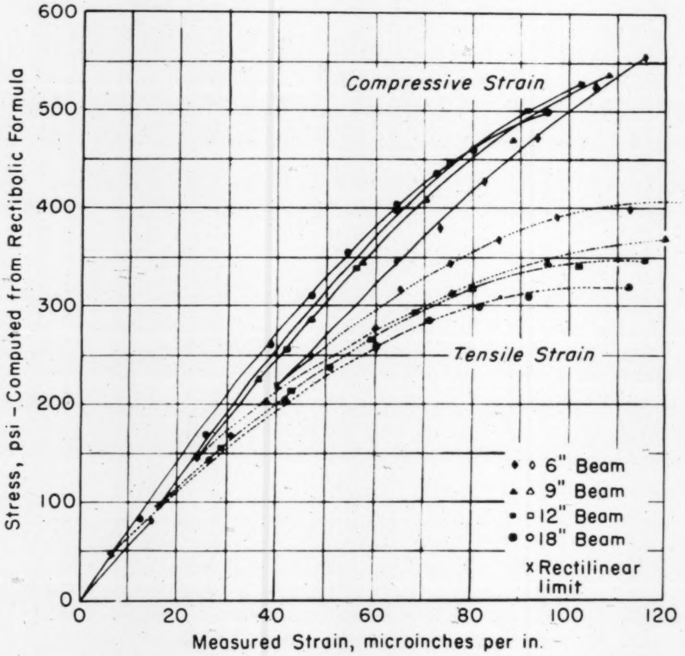

FIG. 8.—Strain Curves For Various Sized Beams Subjected to Bending Stresses.

It is to be expected that the stress-strain curves for concrete do not exactly follow the rule of conventional elasticity, since such materials are only imperfectly elastic. For this reason it is considered more correct to refer to this property in concrete as the rate of change of stress with respect to strain. It is also axiomatic not to entertain any thought of a high degree of precision when dealing with a material as heterogeneous as concrete. It will be noticed that the compressive strain curves in Fig. 8 converged at an ultimate modulus of elasticity of approximately 5,000,000; it is probable that greater precision would indicate these curves as practically coinciding, since they represent only a small per cent of the potential compressive strength of the concrete and have not yet approached the elastic limit. This thought is coupled with the preceding statement that creep is more rapid in small than in large concrete masses which, if there was residual creep not detected in these tests, would cause the compressive strain curves to draw closer together. Conversely, the tensile strain curves are diverging, and the effect of differential potential creep between large and small specimens would create a tendency for greater divergence. It should be noted also that the stresses, against which the measured strains were plotted in Fig. 8, were computed by means of the rectibolic formula. This formula is an ultimate stress formula, since in its derivation the vertex of the parabola was placed at the bottom of the beam. Accordingly, its use for computing stresses less than ultimate and greater than rectilinear limit is not strictly correct, but the effect is not of material significance. Were an adjustment made to represent less than ultimate conditions with greater refinement, the only effect would be to change slightly the shape of the curves in Fig. 8 between the fixed ultimate points and rectilinear limits.

TABLE IV.—MEASURED TEST RESULTS AT FAILURE LOADS, AND PERTINENT DATA COMPUTED THEREFROM.

Size of Beam, in.	Measured Strain, in. per in.		Deflection, in.	Shift in Neutral Axis, in.	Computed Data			
	e_c	e_t			y/d	m	n	R.L.*
6.......	0.000115	0.000124	0.0013	0.11	0.518	1.076	1.47	$0.53f_t$
9.......	0.000108	0.000120	0.0019	0.24	0.527	1.113	1.62	$0.38f_t$
12.......	0.000102	0.000117	0.0024	0.41	0.534	1.147	1.73	$0.27f_t$
18.......	0.000095	0.000112	0.0031	0.75	0.542	1.182	1.85	$0.15f_t$

* Rectilinear limit stress = $(2 - n)f_t$.

The results of measurements at ultimate loads are given in Table IV, together with pertinent additional data computed therefrom. The measured strain readings at each load increment were plotted againt distance from centroidal axis, each size of beam being represented by a sufficient number of specimens to establish a definite trend average. Typical data for the 9-in. beam are plotted in Fig. 9. From similar large-scale graphs the average values of tensile and compressive strain and shift in neutral axis $(y - d/2)$ were determined, the latter being traced by the locus of zero strain. These data are shown in Fig. 10.

The values of ultimate stresses and moduli of elasticity, as computed from measured data, are given in Table V. If all inelastic deformation has not been taken into consideration, E_c will be more nearly constant and E_t will show a greater decrease with depth of beam.

It was mentioned previously that the reduction in breaking stress with depth of beam could result from an increase in the ratio between shift of neutral axis and depth of beam. Data presented in Table IV show that the ratio did increase in these tests with the depth of beam and that the value of n increased accordingly.

Effect of Weight:

Another factor contributing a small amount to reduction in apparent strength with increase in depth of beam is the effect of weight of the beam on the total bending moment. When a concrete beam is loaded to failure using the third-point method, the failure occurs in the middle third of the beam. In this portion of the beam the bending moment is assumed to be of constant magnitude, but if the weight is considered the bending moment

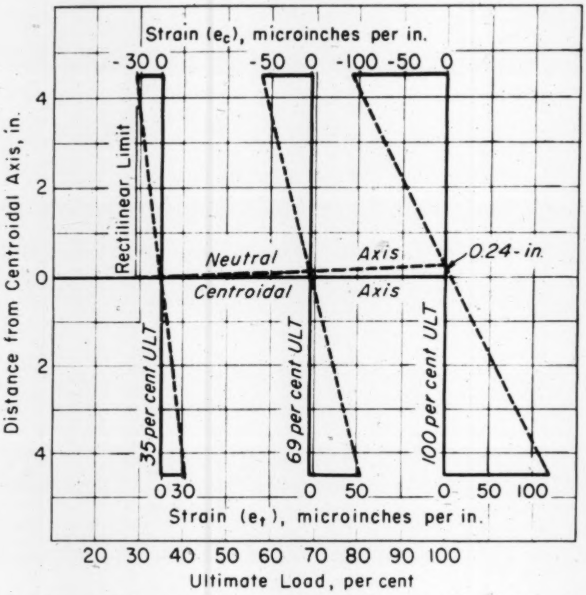

FIG. 9.—Example of Strain Measurements at Different Percentages of Ultimate Bending Strength, the Locus of Zero Strain Traces the Shift in Neutral Axis.

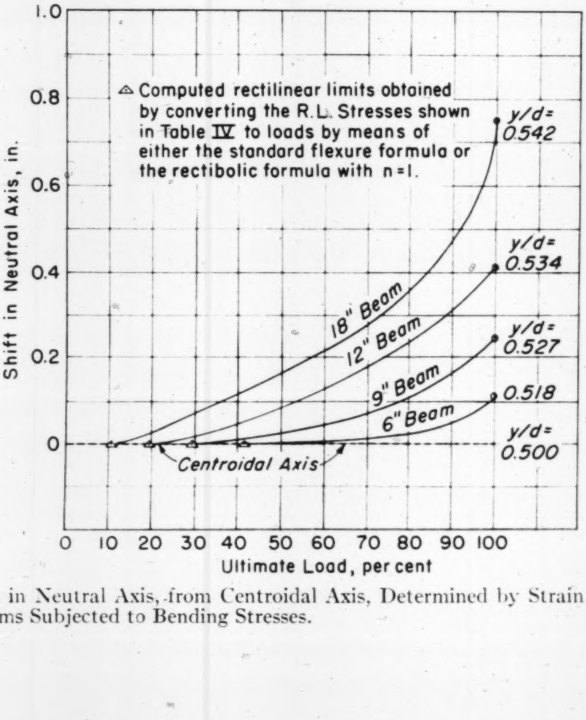

FIG. 10.—Shift in Neutral Axis, from Centroidal Axis, Determined by Strain Measurements on Various Sized Beams Subjected to Bending Stresses.

will be increased by the amount $\frac{wl^2}{8}$ (where w equals the weight of the beam in lb per in.) at the center of the beam. The effect of this increase in bending moment is an increase in stress ranging from near zero for the 6-in. beam to slightly over 1 per cent for the 18-in. beam.

DISCUSSION

Were there no weak elements in the tensile side of the beams, one would expect the beams to break when the tensile stress reached a fixed magnitude for all beams. But measurements have shown, Table IV, that as the beam deepened the neutral axis shifted in increasing proportional amounts. Since, if the tensile stress remains the same and the neutral axis shifts upward, the beam is capable of sustaining more load, it is evident that the average tensile stress reduced as the beam depth increased. Otherwise, instead of withstanding less proportionate loads deeper beams would have withstood larger proportionate loads in comparison with the 6-in. beam.

TABLE V.—UNIT STRESSES AND MODULI OF ELASTICITY COMPUTED FROM MEASURED TEST DATA FOR ULTIMATE LOADS.

Size of Beam, in.	Rectibolic Stresses, psi		Modulus of Elasticity	
	f_c	f_t	E_c	E_t
6	554	405	4 820 000	3 270 000
9	537	368	4 970 000	3 070 000
12	529	348	5 190 000	2 970 000
18	498	318	5 240 000	2 840 000

It may be noted that n, in Table IV, was determined by measuring y and d. Its determination was independent of the stress or the measured strain. It is true that the measured strains appeared to vary with depth of beam, but normally it would not be unreasonable to expect the tensile elements to break when a fixed limiting strain was reached. This would be the case even were there weak elements, hair cracks, or uncemented particles of aggregate in the tension surface, provided that the weak elements failed prior to a load having been attained that was sufficient to rupture the sound elements. The limiting strain, then, of the sound elements would be reached at the time of beam failure. Assuming this to be true and that E_c is constant, relative values of f_t for the various depths of beam may be computed from the following equation:

$$f_t = \frac{E_c e_t}{n} = \frac{K}{n} \quad \ldots\ldots\ldots\ldots (11)$$

where K is a constant.

TABLE VI.—UNIT TENSILE STRESSES FOR VARIATIONS IN n.

Size of Beam	Ratio n	f_t psi (Eq. 11)	f_t (Fig. 7)	
1	2	3	4	
			psi	Per cent
6-in.	1.47	503	503	100
9-in.	1.62	456	441	87
12-in.	1.73	427	419	83
18-in.	1.85	399	396	78

Using $f_t = 503$ psi as computed by means of the rectibolic formula from the actual load shown on Fig. 1 for the 6-in. beam with $n = 1.47$ (as measured), K can be determined.

$$K = 1.47 \times 503 = 739$$

Then

$$f_t = \frac{739}{n} \quad \ldots\ldots\ldots\ldots (11a)$$

Solving for f_t, the results are given in column 3 of Table VI. Column 4 of the table and the dashed curve in Fig. 7

show the ultimate tensile stresses computed from the rectibolic formula using actual test loads (Fig. 1) and values of n determined from measured shifts of the neutral axis as given in Table IV. These data show greater reduction in ultimate tensile stress with increased depth of beam than is the case when n remains constant. The difference may be analogous to statistical explanations made to account for strength varying with beam size.

The results from Eq. 11 check very closely the stresses computed by means of the rectibolic formula from actual test loads as shown in Fig. 7. It should be noted that f_t is the average stress on all of the extreme elements, including the sound and the previously fractured elements as well as the weak ones. This change in average stress is quite consistent with the change in n and therefore appears to be explained by the latter.

TABLE VII.—THEORETICAL VERSUS ACTUAL FAILURE LOADS.

Size of Beam	Theoretical Load, lb, Fig. 1	Actual Load, lb, Fig. 1	Failure Load in Terms of 6-In. Beam, Actual÷Theoretical
6-in.	7 800	7 800	1.00
9-in.	17 550	15 984	0.91
12-in.	31 200	27 456	0.88
18-in.	70 200	59 400	0.85

Thus had there been proportionately no more faulty elements in the larger beams than in the 6-in. beam, it is reasonable to assume that the tensile strength of the outermost elements would have been the same for all depths of beam, as would be the value of n. For this condition, analyses of the rectibolic and conventional moduli of rupture formulae will show that the loads sustained by the test beams of varying size are proportional to bd^2 regardless of which formula is used. In Table VII the theoretical load is the load obtained by means of this proportionality with the load actually carried by the 6-in. beam serving as a base.

From the foregoing it appears that the change in relative load-bearing capacity with change in size of square-section beams having a length-depth ratio of 3 can be determined from the standard flexure formula by application of appropriate factors such as those given in Table VII. Likewise, the equivalent modulus of rupture for a 6-in. beam may be obtained from tests on larger beams by applying these factors to the test loads. Using these adjusted loads, the standard flexure formula is then solved for modulus of rupture.

Conclusions

Within the limits of this investigation on plain concrete beams of varying square cross-section sizes and constant span-depth ratio, it is concluded that:

1. Test results confirm that deeper beams fail at a lower flexural stress than do shallower beams. This is attributed primarily to a differential shift in neutral axis with change in the depth of beam.

2. Design using empirical methods alone should be correlated with tests of a single size of beam. Design derived from theory must give consideration to reduced breaking stress with depth, unless adequately covered by the factors of safety emplyed.

3. Since the compression fibers are never highly stressed, their modulus of elasticity tends to remain substantially constant while that of the tension fibers decreases with increase in depth, resulting in differential ratios of compressive to tensile moduli of elasticity for beams of varying depth.

4. It has been further confirmed that

the conventional flexure formula does not give the true breaking stress. It is believed that the rectibolic formula results in a close approximation to the breaking stress, if the proper values of n are used.

5. This study has confirmed reasonably well the theory that a beam ruptures when the tensile fibers reach a limiting strain.

6. Beams tested in the direction of casting show somewhat higher strength than identical beams tested 90 and 180 deg. from the direction of casting.

7. Comparative load-bearing capacities can be obtained satisfactorily by means of the standard flexure formula if appropriate correction factors found experimentally are used.

8. The standard flexure formula can be used for judging the quality of concrete, but the comparisons for quality should be based upon modulus of rupture of a single size of beam. Tests on beams of other sizes can be equated to the size used for quality determination by application to the loads actually sustained the factors mentioned in conclusion 7.

Acknowledgment:

The work of Messrs. V. D. Edgerton, G. V. Joiner, and H. L. Mayes, of the laboratory staff, in conducting the tests and assisting in making the necessary computations, was of great value in expediting this investigation.

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APPENDIX

DEVELOPMENT OF EQUATIONS FOR DETERMINING THE MOMENT IN A CONCRETE BEAM SUBJECTED TO ULTIMATE LOAD USING COMBINED RECTILINEAR AND PARABOLIC STRESS DISTRIBUTION

1. Moment of tension areas about neutral axis:

$$\text{Triangle:}\quad M_t = \left[\frac{1}{2}\left(\frac{y}{AD}\right)(2f_t - AD)^2\right]\left[\frac{2}{3}\left(\frac{y}{AD}\right)(2f_t - AD)\right]$$

$$M_t = \frac{y^2}{3AD^2}(2f_t - AD)^3$$

$$\text{Rectangle:}\quad M_r = \left[\frac{2y}{AD}(AD - f_t)(2f_t - AD)\right]\left[\frac{1}{2}\,\frac{2y}{AD}(AD - f_t) + \frac{y}{AD}(2f_t - AD)\right]$$

$$M_r = \frac{2y^2}{AD^2}(AD - f_t)(2f_t - AD)(f_t)$$

$$\text{Parabola:}\quad M_p = \left[\frac{2}{3}\left(\frac{2y}{AD}\right)(AD - f_t)^2\right]\left[\frac{5}{8}\left(\frac{2y}{AD}\right)(AD - f_t) + \frac{y}{AD}(2f_t - AD)\right]$$

$$M_p = \frac{y^2}{3AD^2}(AD - f_t)^2(AD + 3f_t)$$

2. T (Moment Arm) $= M_t + M_r + M_p$

$$\frac{y}{3AD}\left(4f_tAD - \frac{AD^2}{2} - 2f_t^2\right)(\text{Moment Arm}) = \frac{y^2}{3AD^2}(2f_t - AD)^3$$

$$+ \frac{2y^2}{AD^2}(AD - f_t)(2f_t - AD)(f_t) + \frac{y^2}{3AD^2}(AD - f_t)^2(AD + 3f_t)$$

$$\text{Moment Arm} = \frac{yf_t}{AD}\left(\frac{f_tAD + AD^2 - f_t^2}{4f_tAD - \frac{AD^2}{2} - 2f_t^2}\right)$$

$$\text{Total Moment} = C\left[\frac{2(d - y)}{3} + \text{Moment Arm}\right]$$

$$M = C\left[\frac{2(d - y)}{3} + \frac{yf_t}{AD}\left(\frac{f_tAD + AD^2 - f_t^2}{4f_tAD - \frac{AD^2}{2} - 2f_t^2}\right)\right]$$

$$M = \frac{f_c(d - y)}{2}\left[\frac{2(d - y)}{3} + \frac{yf_t}{AD}\left(\frac{f_tAD + AD^2 - f_t^2}{4f_tAD - \frac{AD^2}{2} - 2f_t^2}\right)\right]$$

DISCUSSION

MR. C. H. SCHOLER.[1]—I am very much interested in the results secured in this investigation. That a variation was found in the modulus of rupture with increased depth of beam is not too surprising. Usually, the increased depth of beam is brought about by increased sizes of coarse aggregate used in the concrete under test. Probably as the size of aggregate increases, the indicated modulus of rupture will change. Coarse-grained structure in nearly all materials results in lowering the apparent tensile strength of such specimens. It should also be noted that the indicated strength secured from concrete cylinders is higher for small size cylinders and lower for large size cylinders. The effect of size of specimen upon the apparert strength is not a new phenomenon. The apparent indicated strength decreasing with the larger sized members. Dushman, in his Marburg Lecture,[2] discusses some of the theoretical reasons why this may occur.

Another item which should receive more consideration is the proportion of the dimensions of the test specimen for the flexural strength of concrete described in ASTM Method C 78 – 49. This standard provides for third-point loading with the length of span three times the depth, which means that the lever arm producing the moment is the same as the depth. Fundamentally, when we determine the modulus of rupture by applying the equation $R = \frac{Pl}{bd^2}$, we are neglecting the shear effect which becomes quite high in short span beams. Theoretically, the above equation applies only where the beam is small compared with the depth or the transverse dimensions. Most certainly, a beam no more than three times the depth cannot be considered a slender beam, and it will be impossible to separate the shear and tensile stresses. Several years ago, while studying the effect of center loading upon the modulus of rupture, this laboratory studied, by means of photoelastic analysis, the stress distribution under various relations of length of span to depth under center loading. The accompanying Fig. 11 shows the apparent stress distribution for a long, slender beam with third-point loading. Figure 12 shows center loading with a span eight times the depth. Figure 13 shows a span six times the depth. Figure 14 shows a span four times the depth, and Fig. 15 shows a span of two times the depth. It will be noted that the stress distribution as indicated by these photoelastic studies is markedly influenced by the length of the beam. All of the beams shown in Figs. 12 to 15 inclusive were of the same cross-section.

It is entirely possible that in the authors' studies, an appreciable portion of the differences they have observed

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[1] Professor of Applied Mechanics, Kansas State College of Agriculture and Applied Science, Road Materials Laboratory, Manhattan, Kans.

[2] Saul Dushman, "Cohesion and Atomic Structure," Edgar Marburg Lecture, *Proceedings*, Am. Soc. Testing Mats., Vol. 29, Part II, p. 7 (1929).

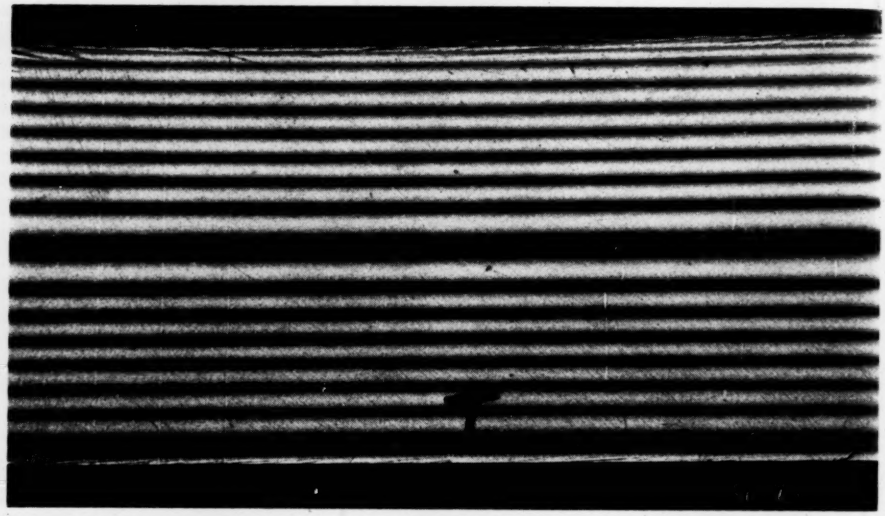

FIG. 11.—The Apparent Stress Distribution for a Long, Slender Beam with Third Point Loading.

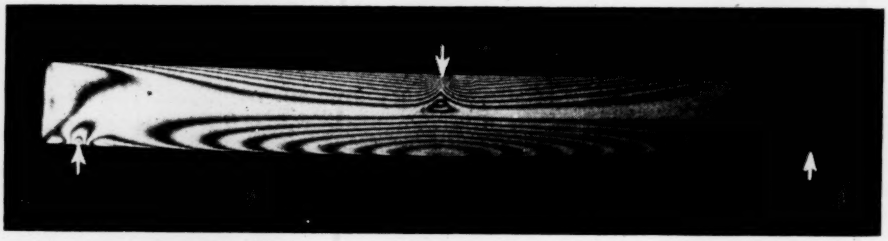

FIG. 12.—Center Loading with a span Eight Times the Depth.

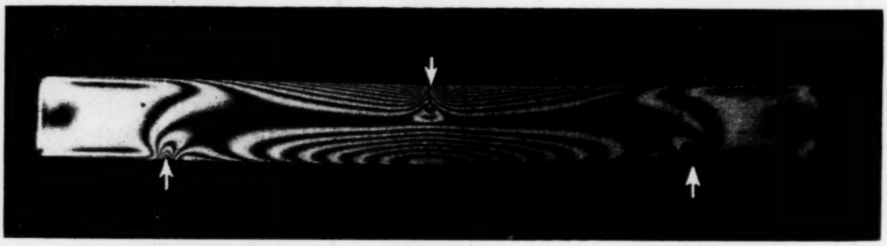

FIG. 13.—Center Loading with a span six Times the Depth.

with different size beams has been accentuated by the fact that the beam is really too short to permit of the proper application of the formula for modulus of rupture. That the variation in size of beams may also be one of the factors involved and that variation in the maximum size aggregates used in the concrete might also be a factor. In some instances, all of these variables are working together, and in all instances the exceedingly small ratio between span length and depth cannot be ignored.

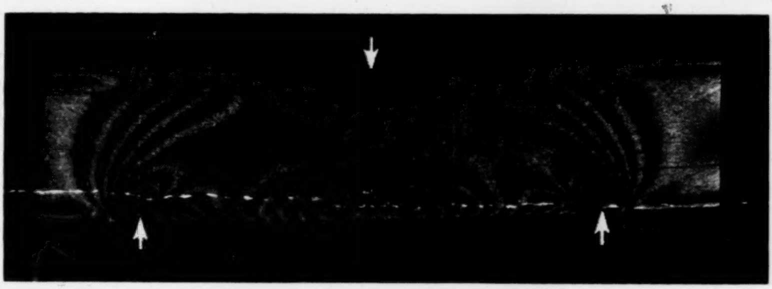
FIG. 14.—Center Loading with a span Four Times the Depth.

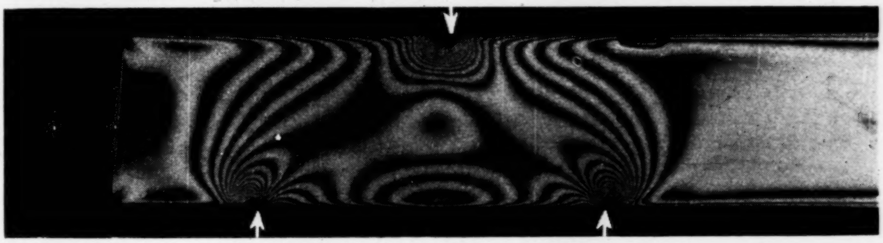
FIG. 15.—Center Loading with a span two Times the Depth.

MESSRS. C. P. LINDNER AND J. C. SPRAGUE (*authors' closure*).—Mr. Scholer has presented very interesting and enlightening supplementary information. With respect to aggregate size, however, since he did not have the full text of the paper, he could not have known that the maximum size of the aggregate used was the same regardless of the size of the beam. This was done specifically in order to eliminate the effect of aggregate size on modulus of rupture. In the final analysis, unlike compressive strength, there is no general trend of flexural strength of concrete with variation in the maximum size of aggregate. If the aggregate has good bond properties and adequate tensile strength, an increase in its maximum size results in the same strength tendency whether the concrete is subjected to compressive or to bending stresses. Conversely, if the aggregate has poor bond properties or is inherently weak, the flexural strength of the concrete should trend in the opposite direction.

It is recognized that in short beams shear is an important factor. However, practically all the beams in this investigation were loaded at the third points, in which case, theoretically at least, the transverse shear is zero between the loads. In almost every case the breaks were between the points of loading, and their directions were essentially normal to the axes of the beams. Therefore they would not appear to be shear breaks. Moreover the transverse shear at failure on the support side of each load averaged 108 psi for the 6-in. beams, 99 psi for the 9-in. beams, 95 psi for the 12-in. beams, and 92 psi for the 18-in. beams. These are not unusually high values and should not have been principal causes of failure.

The photographs submitted, Figs. 12 to 15, show a change in stress distribution with reduction in span-depth ratio. Mr. Scholer failed to state whether or not all these beams were of the same depth. This would appear to be important, as depth would in all probability have an effect on the stress distribution. Until it is known that the depths were the same, the conclusion cannot be drawn that effects on stress distribution illustrated were solely the result of reduction in span or length of beam. The results of loading these beams at the third points would have been interesting also. They would have provided a comparison, between the third points, with the stress distribution in the long slender beam shown in Fig. 11 which was loaded at the third points.

The fact that the modulus of rupture formula did not apply insofar as representing actual breaking stress was a main thesis of the paper. The shortness of the beams, of course, probably has an effect as indicated by Mr. Scholer, but since the span depth ratio was the same for all beams, this would not appear to explain the inconsistent results represented by reducing modulus of rupture with increasing depth of beam. Further research is required to divulge the causes of this phenomenon or to verify the theory expounded in the paper.

The authors express thanks to Mr. Scholer for his contribution.

A METHOD FOR DETERMINING THE MOISTURE CONDITION OF HARDENED CONCRETE IN TERMS OF RELATIVE HUMIDITY*

By Carl A. Menzel[1]

Synopsis

When hardened concrete is exposed to the air, its moisture content tends to attain a state of balance or equilibrium with the relative humidity of the air. Changes in moisture content may be important in various ways, and it is often desirable to have definite information on the moisture condition of the hardened concrete in block, walls, floors, or other building members.

This paper describes a rapid method and simple apparatus for determining the moisture condition of hardened concrete block and expressing the results directly in terms of relative humidity.

The procedure is based on extensive studies to develop the proper apparatus and calibration and testing techniques for making this method as practicable and dependable as possible. As a result, this method gives reliable indications of the moisture condition of concrete block in about 15 to 30 min (if the block is broken into small pieces with a hammer before testing) and usually within 20 min. This is less than 1 per cent of the 48 to 72 hr needed to saturate and then oven-dry block to constant weight as required by present specifications for tests of moisture content and absorption.

With slight modifications, the relative humidity method can be used to determine the moisture condition of hardened concrete at the surface and interior of large specimens such as wall and floor slabs. It can also be used to determine the moisture condition of other construction materials and assemblies affected by relative humidity.

For many years the moisture condition of hardened concrete has been determined by measuring the loss in weight during oven drying and expressing this loss in per cent of the oven-dry weight or in per cent of the total moisture content when the concrete was fully saturated. The process of oven drying and saturating is not only time-consuming but requires an expensive drying oven, sensitive weighing scale, saturating tank, and a means for weighing block while suspended in water. There is also a good probability for error in obtaining and computing the data. Moreover, when the results have been computed, they do not afford the basically sound and significant indication of the moisture condition of the concrete that is needed to determine when it is dry enough for exposure to different service conditions.

To overcome these deficiencies, a rapid method was developed for indicating the moisture condition of concrete using simple and less expensive apparatus. The moisture condition determined by this method is expressed in terms of relative humidity as described in the paper by Gause and Tucker published in 1940 (**1**).[2] By following a few simple directions, the moisture condition of concrete can be determined from a series of readings of the position of a pointer on a graduated scale; no computation of the results is required. The method is particularly useful for determining the moisture condition of individual concrete block and of concrete walls and floors.

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* Presented at the Fifty-eighth Annual Meeting of the Society, June 26–July 1, 1955.

[1] Consultant, Concrete Technical Problems, Portland Cement Assn., Chicago, Ill

The theory and application of the method will be evident from the discussion of the properties of hardened concrete and related matters, comprising Part I of this paper. Part II describes the apparatus, how it is used in testing concrete block, and how it is calibrated. Auxiliary information is given in Appendices I and II on methods for testing the moisture condition of large specimens.

PART I.—INFLUENCE OF RELATIVE HUMIDITY ON THE MOISTURE-VOLUME CHANGE OF HARDENED CONCRETE EXPOSED TO THE AIR

Relative Humidity—Primary Factor in Moisture-Volume Change of Hardened Concrete:

In common with many materials, hardened concrete has a natural tendency to lose or absorb moisture with changes in the moisture content or relative humidity of the air. Concrete that is obviously wet or damp loses a considerable portion of its moisture before it approaches an air-dry condition—a state of balance or equilibrium with the average relative humidity of the surrounding air.

Moisture loss from such wet or damp concrete may or may not be accompanied immediately by shrinkage, depending on the type of concrete. In the case of dense concrete of medium or high cement content, shrinkage usually begins and continues at a fairly constant rate with moisture loss until equilibrium with the air is attained. However, in the case of lean or porous concretes, particularly those made with lightweight aggregates or of the dry consistency used in the manufacture of concrete block, a considerable proportion of moisture can be lost during the early stages of air drying before shrinkage in significant amounts occurs.

With all of the different types of concrete, whether rich or lean, dense or porous, etc., significant shrinkage begins at a moisture content corresponding roughly to the equilibrium value that would ultimately be attained with exposure to a 99 to 100 per cent relative humidity. It continues with further moisture loss until equilibrium with the relative humidity of the surrounding air is established. The lower the final relative humidity, the greater will be the moisture loss and the resulting shrinkage. Hence, as a general rule, shrinkage occurs within the range of equilibrium moisture values from the point where air is saturated with vapor at 100 per cent relative humidity to the point where the air contains no moisture at 0 per cent relative humidity. On the other hand, whenever the relative humidity is increased, the concrete gains moisture and swells until equilibrium is attained.

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[2] The boldface numbers in parentheses refer to the list of references appended to this paper, see p. 1108.

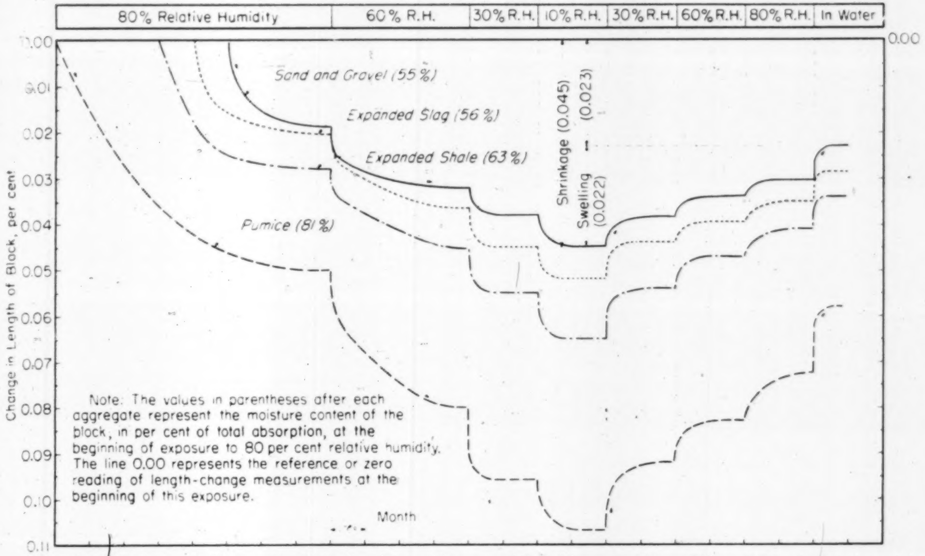

FIG. 1.—Effect of Change in Relative Humidity on Shrinkage and Swelling of Block Made with Light and Heavy Aggregates.

Concrete mixes used yielded the following block per sack: sand and gravel, 25.8; expanded slag, 22.5; expanded shale, 25.9; and pumice 19.5. The strengths at 3 and 28 days in pounds per square inch of gross bearing area were: sand and gravel, 1320 and 1680; slag, 760 and 1250; shale, 1050 and 1520; and pumice, 770 and 920. Block were molded by vibration and pressure in a small single-block machine. They were cured as follows: (1) Immediately after molding, the block were placed in the kiln and allowed to set at 75 F without moisture loss for 2 hr. (2) Saturated steam was then allowed to enter kiln to raise the temperature from 75 to 160 F in 2 hr. (3) Steam flow was adjusted to maintain kiln temperature constant at 160 F for 13 hr. (4) At the end of the 13-hr constant temperature period, the kiln door was opened and block allowed to cool in kiln for 1 hr before removal for further cooling in open air to 75 F. None of the block represented in Fig. 1 were kiln dried.

During cooling the block were drilled for insertion of brass plugs $\frac{3}{8}$ in. in diameter and $\frac{1}{4}$ in. long. These plugs were securely cemented in position with melted sulfur and served as reference points for subsequent length change measurements with the Whittemore strain gage. As soon as the block had cooled to 75 F, they were weighed and initial length readings made to indicate the moisture content and zero reading at the beginning of exposure to an 80 per cent relative humidity. The block remained exposed to the 80 per cent relative humidity until no further length changes were obtained. They were exposed in the same manner to the next lower (or higher) level of relative humidity in the series shown in Fig. 1. Weight readings were made along with length readings.

The moisture contents of the block, in per cent of total absorption, when they were exposed to drying in 80 per cent relative humidity were as follows: sand and gravel, 55; expanded slag, 56; expanded shale, 63; and pumice, 81.

In Fig. 1 only those portions of the time-length change curves are shown which indicate about when constant length was attained during exposure to each relative humidity. Actually the block were exposed to each relative humidity for somewhat longer periods than shown by the curves. These periods are given in the following table:

Aggregate	Actual Time of Exposure to Each Relative Humidity, months							Total Time of Exposure, months	
	80%	60%	30%	10%	30%	60%	80%	80 to 10% R.H. (Shrinking)	30 to 80% R.H. (Swelling)
Sand and gravel	4.0	7.3	2.3	2.6	2.0	2.0	2.0	16.2	6.0
Expanded slag	5.6	7.3	2.3	2.6	2.0	2.0	2.3	17.8	6.3
Expanded shale	7.0	7.3	2.3	2.6	2.0	2.0	2.5	19.2	6.5
Pumice	8.0	7.3	2.3	2.6	2.0	2.0	3.3	20.2	7.3

Hardened Cement Paste an Active Medium, Aggregate Relatively Inert:

A piece of concrete loses or gains water and shrinks and swells with changes in relative humidity largely because the hardened cement paste which binds the aggregate particles together responds to humidity changes. The aggregate in concrete is relatively inert.

The water in a piece of hardened damp concrete exists in three forms: (*a*) chemically combined water, (*b*) free or capillary water, and (*c*) water held on the walls of the *minute* pores in the cement paste. Because of the extreme smallness of the pores and the degree of subdivision of the hydrated cement paste, the paste has the properties of a gel or a colloid in that it absorbs water and swells with increase in relative humidity and loses water and shrinks with decrease in relative humidity.

It may be pointed out that, although the aggregate is relatively inert and the paste is the primary shrinking component of the concrete, the aggregate offers a considerable degree of restraint to the shrinkage of the paste. Hence, other things being equal, a concrete made with a strong, relatively incompressible aggregate will shrink appreciably less than a concrete made with a weak, more compressible aggregate. The higher the modulus of elasticity of the aggregate pieces, the greater will be their resistance to compression by the shrinkage of the surrounding paste. Thus, as a general rule, heavyweight aggregate concretes will shrink less than lightweight aggregate concretes.

Besides the influence of the type of aggregate used, the shrinkage of a piece of concrete during drying in air depends on the *potential* shrinkage of the paste. For curing at normal temperatures, this depends on a number of factors but mainly on the water content of the fresh paste and to a minor degree on the chemical composition of the cement. Any increase in the water content increases the shrinkage. If concrete is cured in high-pressure saturated steam at, say, about 120 psi and 350 F for approximately 8 hr, the pore structure of the paste is altered so that shrinkage is very materially decreased.

It will be clear from the above that with all types of concrete changes in relative humidity cause changes in the moisture content of the hardened cement paste which result in shrinkage with moisture loss and swelling with moisture gain.[3]

Effect of Change in Relative Humidity on the Shrinkage and Swelling of Concrete Block:

The curves in Fig. 1 illustrate several points made in the preceding discussion, particularly as they apply to concrete of the type used in concrete block.[4] They show the shrinkage in length which occurred when partially saturated concrete block, made with four different aggregates, were exposed progressively to 80, 60, 30, and 10 per cent relative humidity and how these same block then underwent swelling during progressive exposure to 30, 60, and 80 per cent relative humidity before final immersion in water. Further details of the test conditions are given in the notes for Fig. 1.

The curves clearly reveal the humidity-sensitive nature of this concrete. With each exposure to a lower or higher level of relative humidity, shrinkage or swelling of the concrete began promptly and continued at a diminishing rate until it ceased as equilibrium was attained.

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[3] Experimentation in progress at the Portland Cement Assn. laboratories indicates that carbonation affects volume stability. These studies are being pursued.

[4] The curves in Fig. 1 were assembled from Fig. 3(*a*), (*b*), (*c*), and (*d*) in a paper by Shideler (**16**) reporting the results of tests made by the laboratories of the Portland Cement Assn.

The curves also show the influence of type of aggregate used on the shrinkage and swelling characteristics of the block and indicate that greater shrinkage and swelling was obtained with a compressible aggregate, such as pumice, than with the less compressible sand and gravel.

Although all of the curves indicate shrinkage with decrease in relative humidity and swelling with increase in relative humidity, the shrinkage with a given type of aggregate from a partially saturated (100 per cent relative humidity) condition to equilibrium with 60 per cent relative humidity was about three times greater than the swelling which occurred later from equilibrium with 60 per cent relative humidity to final immersion in water. On the other hand, only minor differences between shrinkage and later swelling are shown by the curves for humidity changes from 60 to 10 per cent relative humidity and from 10 to 60 per cent relative humidity.

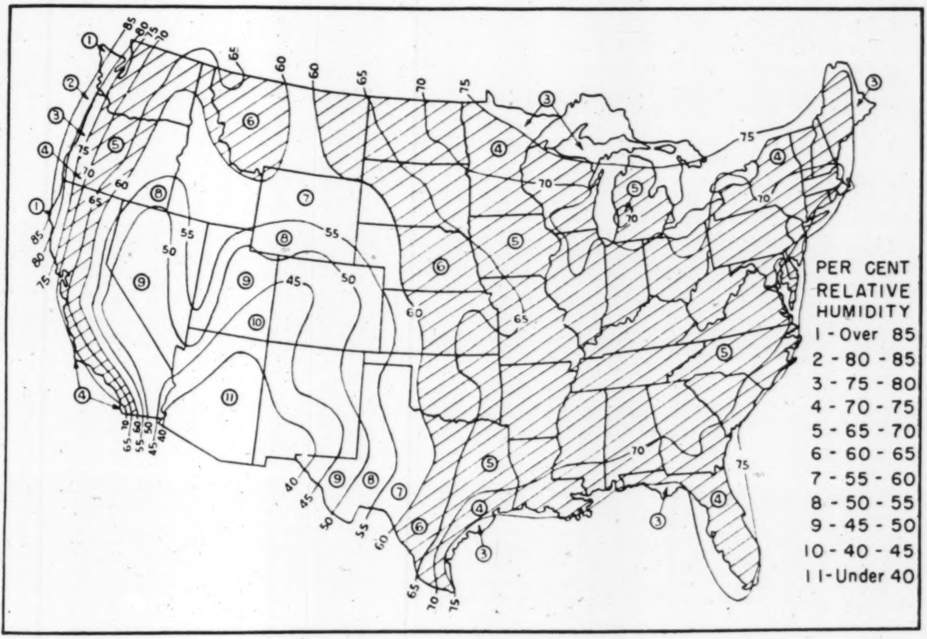

FIG. 2.—Average Annual Relative Humidity.

Shrinkage Minimized by Drying to Approximate Moisture Condition Attained in Service:

The curves in Fig. 1 and those available from other sources (10, 11, 12) strongly suggest that the drying shrinkage and the possibility of cracking in concrete masonry walls can be minimized by drying the individual units to the average moisture content they would attain in service. This simple concept, long practiced in the wood, paper, and textile industries, is based on the fact that the moisture content of concrete masonry walls exposed to the air is more closely related to *relative humidity* than to any other single factor except where the concrete is exposed to alternate soaking and drying. Since masonry walls are generally exposed to continuously changing conditions, their moisture content is not static but is constantly shifting in an attempt to remain in balance with variations in the relative humidity of the air to which they are exposed. For this reason the concrete masonry units intended for a wall in a given location should be dried to a moisture content at least as low as the point *midway* between the high and low extremes attained in service. For all practical purposes, this represents the moisture condition that would be attained at equilibrium with the *average* relative humidity to which the wall is exposed in that location.

The map in Fig. 2 shows the average annual relative humidities for various regions of the United States. The cross-hatched regions embracing the areas marked 4, 5, and 6 are regions where the average annual relative humidity ranges from 60 to 75 per cent. These regions cover most of the country except the dry areas in the Southwest and the damp areas along the seacoasts. A map of this type indicates to what moisture condition block should be dried to minimize moisture shrinkage in walls exposed to outdoor air. Of course, for interior walls exposed on both sides to inside air, the block should be dried to the approximate moisture condition they will attain with the average relative humidity of inside air.

In cold weather the relative humidity of inside air may reach a low value—of the order of 10 to 30 per cent for heated buildings in northern climates—particularly if there is no provision for humidifying the air to moisten it to comfort levels. In heated buildings the walls will be exposed for about 5 months (May 1 to October 1) to the relative humidity of *outside* air and for about **7** months (October 1 to May 1) to the relative humidity of heated *inside* air. The midway point between these seasonal relative humidities may lie between 50 and 60 per cent.

PART II.—DESCRIPTION AND USE OF MOISTURE-HUMIDITY INDICATING APPARATUS IN TESTING CONCRETE BLOCK

In the practical application of the concept described in Part I for minimizing drying shrinkage, it is necessary to have some reliable way of determining when concrete masonry units are dry enough for the average relative humidity expected under service conditions. For this and other purposes, it appears highly desirable that the moisture condition of the concrete should be determined and expressed directly in terms of relative humidity. Moreover, the determination should be made in a minimum of time and with accurate but relatively inexpensive apparatus.

Outline of Method and Apparatus:

Such a method and apparatus are illustrated by the diagrams of Fig. 3. A block, representative of the group whose moisture condition is desired, is broken with a hammer and cold chisel into small pieces or lumps ranging from $\frac{3}{4}$ in. to 2 in. in maximum dimension. These freshly broken lumps are promptly placed in an expanded metal pail which is then sealed in a vaportight metal container having a quick-closing cover provided with a blower with external motor. The blower circulates the air inside the container to facilitate an interchange of moisture between the air and concrete lumps and to reduce the normal lag in response of the humidity-sensitive element of the hygrometer. This interchange continues until an approximate balance between the moisture in the concrete and the relative humidity of the air in the container is attained.[5] The per cent relative humidity is indicated by the position of the pointer on the graduated scale of a suitable hygrometer under the cover. All readings of relative humidity are corrected by a calibration curve based on periodic tests of the hygrometer against known relative humidities which are established within the container by five saturated salt solutions.

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[5] To provide good circulation and clearance, the volume of the container should be from three to four times the gross volume of the broken concrete lumps. Under these conditions the

During the test a series of spot readings of relative humidity are made at definite periods and, after correction, are plotted promptly to provide a time-humidity curve for indicating the trend toward a final relative humidity, that is, where the curve levels off to a constant value. The final relative humidity, indicating the moisture condition of the block, is attained in about 15 to 30 min and usually within 20 min. Hence, this significant and realistic information can be obtained in less than 1 per cent of the 48 to 72 hr needed to saturate and then oven-dry block to constant weight as required by present specifications.[6]

Application of Test Results:

The usefulness of the test may be illustrated by a few examples. If the hygrometer should indicate a final relative humidity of, say, 70 per cent, this means that the block is dry enough to experience little if any shrinkage from drying if it goes into a wall exposed to an average relative humidity of 70 per cent. Similarly, if the hygrometer indicates a final relative humidity of 50 per cent, the block is dry enough for use in a wall exposed to an average relative humidity of 50 per cent. However, if the hygrometer indicates 90 per cent relative humidity, then the block is too damp for use in a wall that is normally exposed to an average relative humidity of 70 per cent or lower. Hence, this method quickly indicates if a group of block are dry enough for the average relative humidity to which they will be exposed in service. The same method will also indicate when block are at the desired moisture condition for the application of glazes and metal surfaces or for other purposes where moisture condition is to be controlled or determined.

Other Features of Method:

In addition to its simplicity of operation, the apparatus can be easily calibrated or checked for accuracy and can be used under a variety of conditions. For instance, it can be used to determine the moisture condition of block soon after sample block have been selected, or if desired, the test can be made at any convenient later time. In that case, each

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concrete normally contains several hundred times more moisture than would be required to saturate the air within the enclosure. Hence, the concrete has ample capacity to raise or lower the relative humidity of the air quickly to correspond with the relative humidity of its own moisture, particularly when the moisture is uniformly distributed in the concrete. Of course, the container and all other parts of the apparatus within it must be made of nonhygroscopic materials.

[6] Tests have shown that the indicated relative humidity of broken lumps of concrete block was virtually the same as the relative humidity to which block had been exposed, regardless of type of aggregate or method of curing. In one group of tests, block had been exposed for about 9 months in a room maintained at 50 per cent relative humidity (±2 per cent). Broken lumps from these block indicated the following relative humidities: sand and gravel, 52.6 per cent; expanded slag, 52.0 per cent; expanded shale, 50.8 per cent; bituminous cinders, 53.0 per cent; and pumice, 53.4 per cent. At the time of the test, the two Serdex hygrometers used indicated 50.5 and 51.0 per cent relative humidity in the room.

In another group of tests, six block made of volcanic cinders had been stored in outdoor air at El Paso, Tex., for 3 weeks, during which relative humidities at the local weather station averaged 27.9 per cent. Broken lumps of the block indicated from 21.5 to 32.5 per cent relative humidity and averaged 27.3 per cent. The three lowest values of relative humidity in the concrete (21.5, 24.5, and 25.5 per cent) were below that of the surrounding air and probably resulted from exposure of the block to hot sunshine.

Good checks in relative humidity readings (within ½ per cent relative humidity) were obtained on the same concrete block samples when tested consecutively in two different moisture-humidity apparatuses.

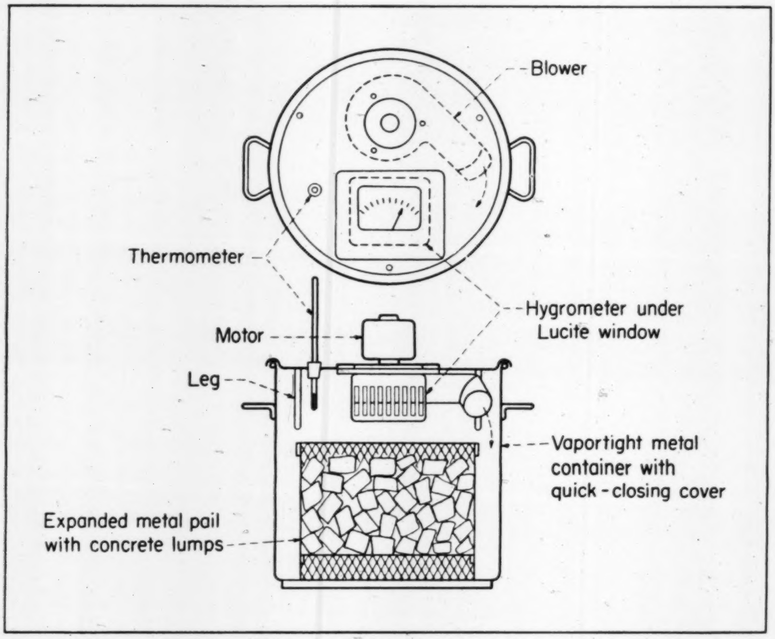

Fig. 3.—Relative Humidity Method of Test for Moisture Condition of Concrete Block.

sample block after selection is stored and sealed immediately in a closed metal container to prevent moisture change. Each block can then be transported to the laboratory or place where the apparatus is located and tested in the prescribed manner.[7]

The apparatus can be assembled from readily available standard parts and materials at less than half the cost of the drying oven, weighing scale, saturating tank, and other items necessary for the conventional moisture test on concrete block.

DETAILS OF METHOD AND APPARATUS

The preceding description has given a general outline of the method and apparatus. More detailed information is given in the following paragraphs with the aid of illustrations in Figs. 4 to 8 and Sample data Sheees 1 to 5.

The procedure is based on extensive studies that were made to develop the proper apparatus, calibration, and testing technique for making the method as practicable and dependable as possible.[8]

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[7] When moisture loss is prevented, a delay of 24 to 72 hr before testing is not considered to introduce any significant error in the moisture condition of the concrete. Of course, it is important, in the interim period between selection and testing of the block samples, that the block in the stockpile be protected from rain or other wetting so that they will remain as dry as the sample block tested. Obviously, the testing of the block at a central point will reduce the possibility of damage to the apparatus which may occur during transportation and at the job site as a result of rough handling and exposure to wetting and extremes of temperature.

[8] The apparatus was used under a variety of conditions at 17 geographical locations in various regions of the United States. Tests of the moisture condition of 410 blocks were made with 13 pieces of apparatus at 18 block plants and laboratories. The blocks were made with practically all of the different types of dense and lightweight aggregates, both natural and artificial, commonly used for making block in the United States in 1952 and 1953. The results of these extensive studies in both field and laboratory are contained in an unpublished report on file at the Portland Cement Assn. (**15**).

General Requirements for Tests:

(*a*) Before the apparatus is used for testing block for the first time, *the hygrometer must be calibrated.* It must also be calibrated periodically later. By calibration is meant testing for accuracy and establishing any corrections to be applied to scale readings.

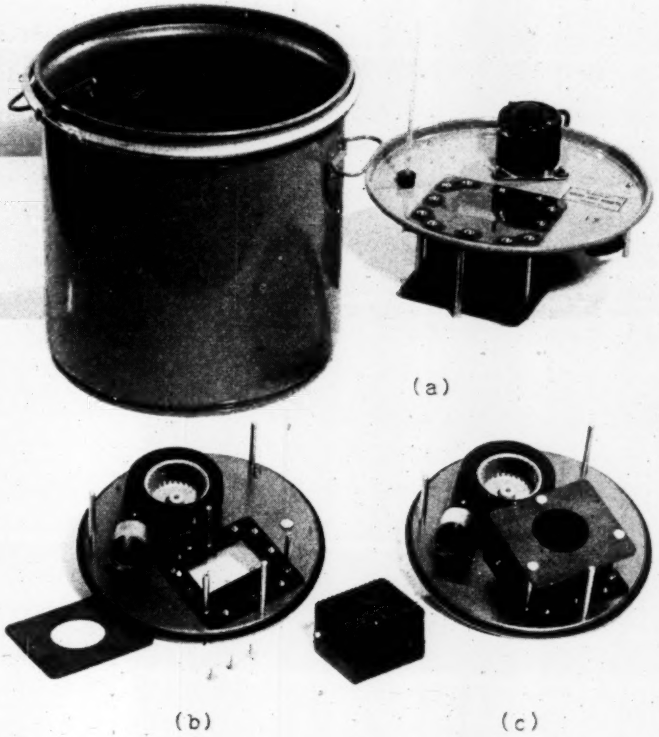

FIG. 4.—Container and Cover Assembly of Apparatus.

(*a*) General appearance of container with lever-locking ring and top of cover assembly with motor for blower, Lucite window for viewing scale of hygrometer, and thermometer for indicating temperature within container during test.

(*b*) and (*c*) Bottom of cover assembly showing location of blower for circulating air in container and also how Serdex hygrometer is mounted and held in position under Lucite window. The three legs for supporting cover assembly are also shown.

(*b*) The tests (whether on block or for calibration) should be conducted in a room which can be maintained at a fairly constant temperature during each test, that is, within 5 F of the average room temperature. Preferably, the average room temperature should be not less than 65 F nor more than 85 F.

(*c*) Both the apparatus and concrete block specimens should be at the average room temperature before the beginning of the test.

(*d*) Each block specimen should be stored in a vaportight container (or wrapped in a plastic sheet) to protect it from moisture change prior to test and during the period required to attain room temperature.

(*e*) The room should be provided with a table about 30 in. high, 24 in. wide, and 48 in. long, with the top of nonabsorptive surface and level in all directions, on which the apparatus is placed during test to facilitate reading and recording relative humidity and temperature within the container.

(*f*) A timer should be available that tilts on its base for easy viewing and that has a large readable dial, sweep second hand, and a minute hand to make readings at desired time intervals up to 60 min.

(*g*) Data should be recorded and plotted in a systematic manner as illustrated in sample data sheets Nos. 1 to 5.

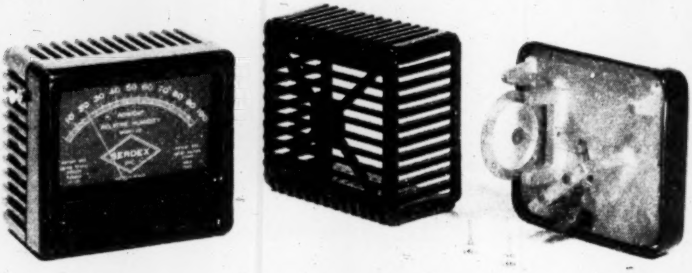

FIG. 5.—Serdex Hygrometer and Its Assembly.

Left view shows front of hygrometer and the pointer which indicates relative humidity on a scale graduated in 1 per cent divisions. Right view shows the appearance of back of hygrometer with grilled cover (center view) removed to reveal humidity-sensitive diaphragm and multiplying linkage connected to pointer.

Apparatus:

Container and Cover Assembly.—Various details of design and cover assembly will be apparent from Fig. 4. The container shown is a standard 8-gal steel container $13\frac{5}{8}$ in. in diameter by $13\frac{1}{4}$ in. high inside with two hinged handles. The motor for driving the blower is mounted on top of the cover to insure cool operation and should itself have cool operating characteristics. The vertical drive shaft from the motor to the blower passes through a suitable stuffing box in the cover to keep it vaportight during test. A Koroseal rubber gasket is clamped between the perimeter of the Lucite window and the cover to provide a vaportight joint.[9]

Hygrometer.—The hygrometer shown in Fig. 5 is of the mechanical type.

NOTE.—The Serdex "Laboratory Standard Model" hygrometer is based on the change in dimension of a circular diaphragm of animal membrane (goldbeater's skin) with changes in relative humidity. It is entirely contained in a molded plastic case $4\frac{1}{2}$ by 4 by 3 in. deep with numerous openings or grills for ventilation. The diaphragm is clamped between two metal rings having an internal diameter of $1\frac{1}{2}$ in.; its surface forms a flat truncated cone. Movements of the apex of this conically-shaped diaphragm with changes in relative humidity are transmitted to the indicating pointer by a multiplying linkage which is arranged to place the diaphragm under slight spring tension. The red pointer moves over a scale of white figures and divisions on a black ground. The scale is 3.3 in. long and is graduated in 1 per cent divisions from 0 to 100 per cent R.H. with graduations numbered at each multiple of 10 per cent.

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[9] Harold H. Steinour of the Portland Cement Assn. laboratories has shown that when the enclosure provided by the 8-gal container contains a source of water vapor—from a broken concrete block specimen, for example, or from a saturated salt solution—simple diffusion through small openings totaling 0.1 sq cm would not introduce a significant error in the relative humidity developed within the enclosure. However, as a general precaution, care should be taken to prevent vapor loss-or-gain from the enclosure, particularly if means are provided for circulating the air within the enclosure.

Miscellaneous Items.—Expanded metal pail, timer, sieve, thermometers, several 10-gal storage containers, large plastic tray, five calibrating salts, solution bottles, data sheets, etc., are also needed.

Calibration of Hygrometer:

The indications of the hygrometer (like those of any sensitive instrument) should be checked periodically against known relative humidities within the range of its normal use and corrected as necessary by a calibration curve. Hygrometers have a tendency to change with time and use.

A convenient and inexpensive method of securing a known relative humidity is by the use of certain saturated salt solutions listed in Table I. These salts are the same as those recommended by Wexler and Brombacher (6) for calibrating mechanical type hygrometers. The values of relative humidity for a given salt in Table I are for 77 F; they will vary slightly with temperature. They are taken from Table II of a recent paper by Wexler and Hasegawa (9).[10]

Preparation of Salt Solutions.—Table I gives the volume of distilled water and weight of salt crystals required to provide an 8-oz solution of the "slushy" consistency desired with each salt. The exact volume of water should first be measured in a milliliter graduate and poured into a solution bottle. The required weight of salt should then be gradually added to the water. With lithium chloride the solution of crystals in water is accompanied by a marked heating effect, and with magnesium and potassium nitrate there will be a marked cooling effect. Each salt solution should be allowed to attain room temperature before use. Salt crystals will settle to the bottom of the bottle and comprise from one half to two thirds of the volume of the mixture as illustrated in Fig. 6(*a*).

TABLE I.—PREPARATION OF SATURATED SALT SOLUTIONS.

NOTE.—The amount of water and salt listed will provide an 8-oz mixture of saturated liquid and salt crystals nearly filling each bottle. When thoroughly stirred, the mixture will be of the "slushy" consistency required for calibration with the large tray. When allowed to settle, the salt crystals will comprise about 60 per cent of the height of the mixture.

Kind of Salt	Volume of Distilled Water, ml	Weight of Salt Crystals, g	Relative Humidity Established in Closed Container, per cent
Lithium chloride, $LiCl \cdot H_2O$	120	195	12.0
Magnesium chloride, $MgCl_2 \cdot 6H_2O$	40	275	33.0
Magnesium nitrate, $Mg(NO_3)_2 \cdot 6H_2O$	55	270	53.5
Sodium chloride, $NaCl$	125	220	75.5
Potassium nitrate, KNO_3	124	220	92.0

[a] These values are for 77 F but will vary slightly with temperature. The humidities established will decrease slightly with increase in temperature and, conversely, increase slightly with decrease in temperature but will be within 1½ per cent R.H. of indicated values at temperatures ranging from 67 to 87 F. This variation is considered to be negligible.

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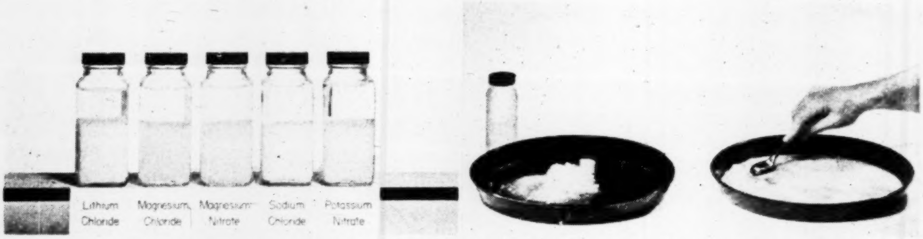
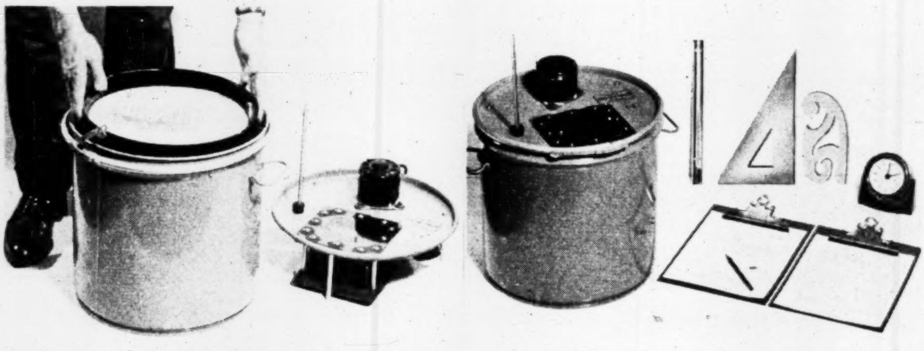
[10] This paper gives reliable data on relative humidity–temperature relationships for the five salts in the temperature range of 32 to 122 F (0 to 50 C). From this and other sources (4, 5, 6, 8), it appears that these salts have a low temperature coefficient and that they will provide relative humidities within 1½ per cent of the indicated values in Table I at temperatures ranging from 67 to 87 F. Of course, only distilled water and chemically pure salts (analytical reagent quality) must be used in making up these calibrating solutions.

Of course, each bottle should be properly marked as to salt solution and should be sealed with a cap except when the solution is actually being removed or returned to the bottle.[11]



(*a*) Five 8-oz bottles of saturated salt solutions.

(*b*) and (*c*) Slushy mixture is removed from its bottle and spread evenly over bottom of plastic tray with aid of spoon.



(*d*) Tray is lowered into container of apparatus until it rests concentrically on bottom of container.

(*e*) Sealed container of apparatus and other items used as they appear during calibration test.

FIG. 6.—How Salt Solutions Are Used in Calibrating Hygrometer.

Calibration Procedure.—The calibration procedure is the same for each salt solution. It is desirable to begin with lithium chloride and continue with each salt in the order listed in Table I to establish the next highest level of relative humidity.

First, thoroughly stir the crystals and liquid in the solution bottle and deposit all of the mixture at the center of a plastic tray, as in Fig. 6(*b*), and seal the bottle. Spread the slushy mixture as evenly as possible over the bottom of the tray as in Fig. 6(*c*), and lightly jolt the tray flatwise a few times on the table.

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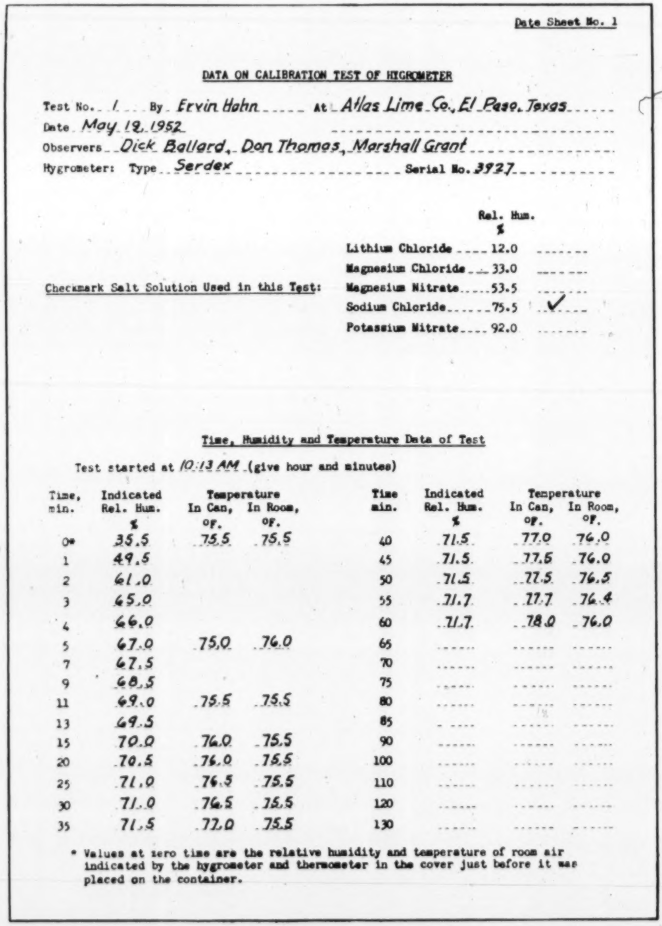
[11] Preferably the solution bottles should be of flint glass with a wide mouth about 1¼ in. in internal diameter; they should be square, medium tall (about 5½ in. closed), and have a threaded neck with black bakelite screw caps provided with chemically resistant liners over white paper pulp pads. A stainless steel spoon should be available with handle long enough to loosen and stir salt crystals at bottom of solution bottle. This spoon is also useful in returning salt crystals and liquid from plastic tray to bottle after each calibration test.

Normally, the salt solutions need to be prepared only once (at the time of the initial calibration) or at very infrequent intervals since they are durable and can be reclaimed with only slight loss after each calibration test. However, there will be some loss, and this can be replenished from time to time by adding a small amount of salt crystals and distilled water so that the total volume of the mixture will be 8 oz and the salt crystals will comprise from one half to two thirds of the volume of the mixture as illustrated in Fig. 6(*a*).



Data Sheet No. 1

DATA ON CALIBRATION TEST OF HYGROMETER

Test No. 1 By Ervin Hahn At Atlas Lime Co., El Paso, Texas
Date May 19, 1952
Observers Dick Ballard, Don Thomas, Marshall Grant
Hygrometer: Type Serdex Serial No. 3927

Checkmark Salt Solution Used in this Test:

	Rel. Hum. %	
Lithium Chloride	12.0	
Magnesium Chloride	33.0	
Magnesium Nitrate	53.5	
Sodium Chloride	75.5	✓
Potassium Nitrate	92.0	

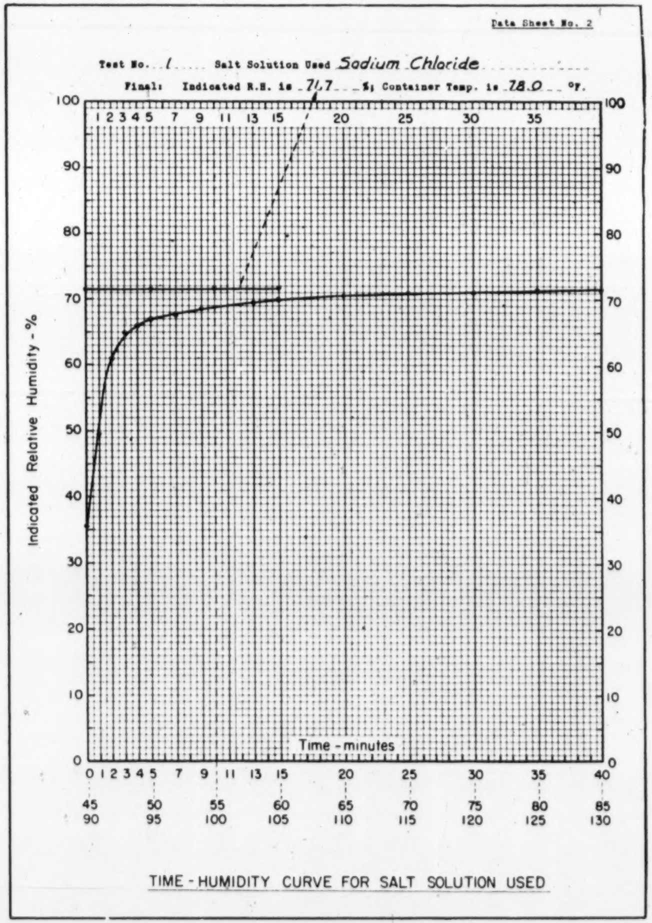
Time, Humidity and Temperature Data of Test

Test started at 10:13 AM (give hour and minutes)

Time, min.	Indicated Rel. Hum. %	Temperature In Can, °F.	Temperature In Room, °F.	Time min.	Indicated Rel. Hum. %	Temperature In Can, °F.	Temperature In Room, °F.
0*	35.5	75.5	75.5	40	71.5	77.0	76.0
1	49.5			45	71.5	77.5	76.0
2	61.0			50	71.5	77.5	76.5
3	65.0			55	71.7	77.7	76.4
4	66.0			60	71.7	78.0	76.0
5	67.0	75.0	76.0	65			
7	67.5			70			
9	68.5			75			
11	69.0	75.5	75.5	80			
13	69.5			85			
15	70.0	76.0	75.5	90			
20	70.5	76.0	75.5	100			
25	71.0	76.5	75.5	110			
30	71.0	76.5	75.5	120			
35	71.5	77.0	75.5	130			

* Values at zero time are the relative humidity and temperature of room air indicated by the hygrometer and thermometer in the cover just before it was placed on the container.

Data Sheet No. 1



Data Sheet No. 2

Test No. 1 Salt Solution Used Sodium Chloride
Final: Indicated R.H. is 71.7 %; Container Temp. is 78.0 °F.

TIME - HUMIDITY CURVE FOR SALT SOLUTION USED

Data Sheet No. 2

The crystals will be barely, if not quite, covered with liquid.[12]

Place the open container on the floor (leave cover on table). Lower the tray with salt solution into the container as shown in Fig. 6(*d*) until it rests concentrically on the bottom of the container. Replace the container on the table. This should be level at all times during the calibration test so that the salt mixture will remain evenly spread over the entire area of the bottom of the tray.

On data sheet No. 1, record at 0 min the reading of relative humidity and temperature of room air indicated by the hygrometer and thermometer in the cover just before it is placed on the container. Also record the temperature of the regular room air thermometer suspended near the apparatus.

NOTE.—The pointer of the hygrometer will attain a balanced position more readily if the Lucite window above the hygrometer is lightly tapped with the fingers while making the reading. Readings should be based on the position of the center of the pointer with reference to the scale divisions. All hygrometer readings should be read to the *nearest half percentage point* of the humidity scale and all temperatures to the *nearest degree Fahrenheit.*

Place the cover on the container and seal it with the lever-locking ring. Wind the timer and set at 0, then start the timer and plug in the blower motor. The apparatus will appear as in Fig. 6(*e*). Make a series of spot readings of relative humidity within the container at the exact time in minutes listed on data sheet No. 1. Temperatures within the container and those of room air should be read at approximately 5-min intervals and recorded.

As soon as time permits, use data sheet No. 2 to plot each value of indicated relative humidity against the corresponding time in minutes. Then with the aid of an irregular curve, draw a representative curve through the plotted points to obtain the time-humidity curve for the calibration test with the salt solution used. Continue the test until the curve has definitely leveled off to a constant value (that is, within ½ percentage point of humidity) for a period of 15 min. This value represents the indicated relative humidity to be used in preparing the calibration curve and should be recorded as shown at the top of data sheet No. 3 together with the test number, date, final temperature in the container, and salt solution used.

NOTE.—Normally, the time-humidity curve levels off to a constant value by the end of 60 min for the test with lithium chloride, magnesium chloride, and potassium nitrate. With magnesium nitrate and sodium chloride, the time-humidity curve usually levels off by the end of 30 to 45 min.

At the conclusion of the test with each salt, stop the timer, unplug the blower, and remove the cover and place it on the table. Place the container on the floor, remove the tray with salt solution, and return all of the solution and crystals to the proper bottle. Seal the bottle, rinse the tray and spoon with clean water to remove all salt, and wipe dry with a clean cloth. Wipe the inside of the container with a clean dry cloth, set on the table, and replace the cover until the test with the next salt is begun.

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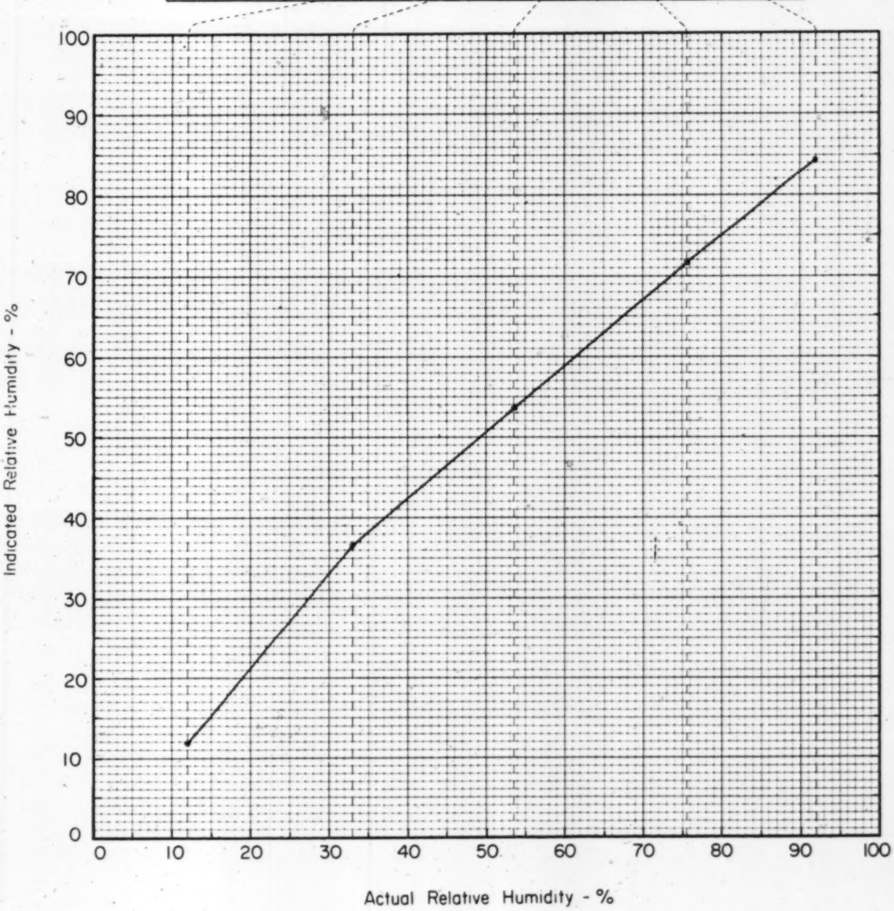
[12] A Bolta No. 12-R brown plastic tray 12⅞ in. in outside diameter and 1¼ in. deep, with flat bottom 11⅜ in. in inside diameter has been found to be particularly well suited for holding salt solutions during calibration of the hygrometer. This plastic tray is inherently tough and durable and resists attack by the various salt solutions used. It provides the large area desired for exposure of the salt solution, yet provides enough clearance within the walls of the steel container so it can be readily moved in and out of the container for the calibration tests. The surface of this tray is smooth and glossy, making it possible to return practically all of the salt solution to the storage bottle for later use. The liquid pours easily from the well-rounded rim of the tray without spillage.

Data Sheet No. 3

Table of Results of Calibration Test with Each Salt

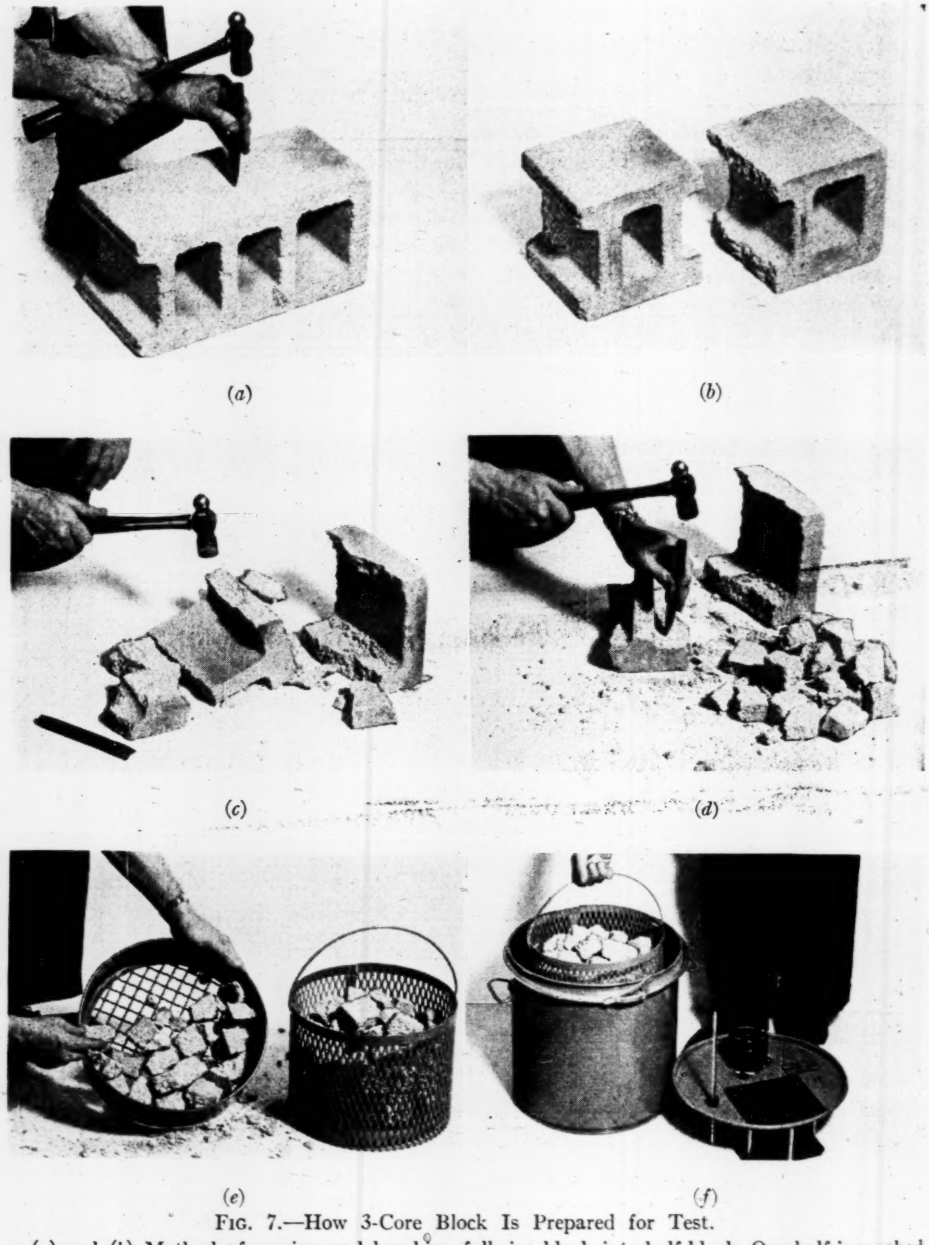
Hygrometer: Type Serdex Serial No. 3927

Salt	Lithium Chloride	Magnesium Chloride	Magnesium Nitrate	Sodium Chloride	Potassium Nitrate
Test No.	5	4	3	1	2
Date	5-19-52	5-19-52	5-19-52	5-19-52	5-19-52
Final Temp.	82 F	81 F	81 F	78 F	80 F
Final R.H.	11.8 %	36.5 %	53.5 %	71.7 %	84.4 %



CALIBRATION CURVE FOR CORRECTING RELATIVE HUMIDITY INDICATED BY HYGROMETER

Data Sheet No.3



(a) (b) (c) (d) (e) (f)

FIG. 7.—How 3-Core Block Is Prepared for Test.

(a) and (b) Method of scoring and breaking full-size block into half block. One half is marked and stored in a vapor tight container for future tests.

(c) and (d) One half is broken into lumps ranging from $\frac{3}{4}$ to 2 in. with hammer and cold chisel. Any discoloration from moisture is noted.

(e) and (f) Lumps are screened to remove dust and particles, placed in expanded metal pail, and lowered concentrically within container of apparatus for test.

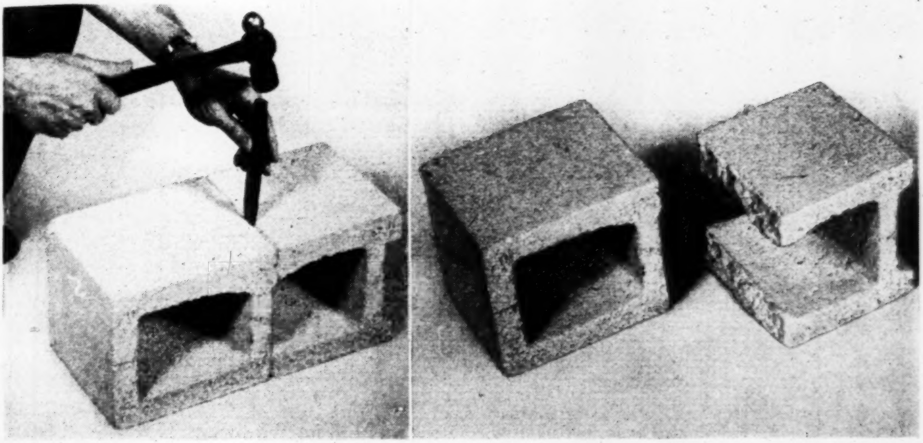

(a) (b)

FIG. 8.—How 2-Core Block Is Prepared for Test.

The larger portion is marked and stored in a vaportight container for future tests. The smaller portion is broken into lumps and handled in same manner as shown in Fig. 7.

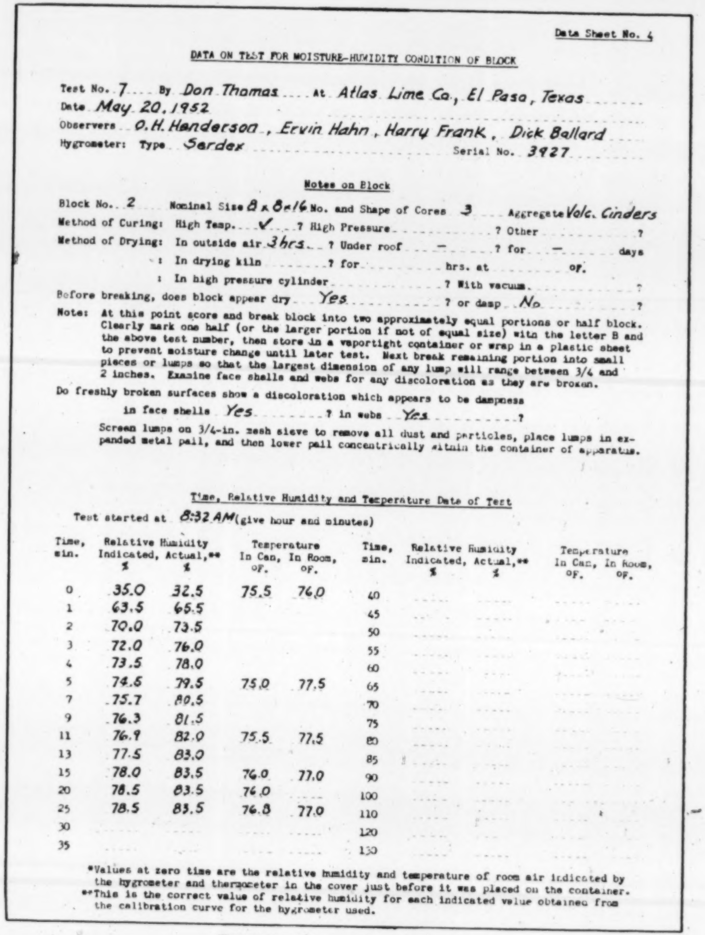
Preparation of Calibration Curve.—On data sheet No. 3, plot the tabulated value of indicated relative humidity (on the vertical scale) against the actual relative humidity (marked by light dotted lines on the horizontal scale) for each salt. Then connect the individual points by straight lines to obtain the calibration curve for the hygrometer used, as on sample data sheet No. 3.

Procedure for Determining Moisture Condition of Concrete Block:

Preliminary Treatment of Test Specimen.—Immediately after selection of representative full-size block specimens, seal each block sample in a separate vaportight metal container for storage until test. Remove the sealed container with the block to the test room well in advance of the test so that it can attain the temperature of the test room and apparatus. This is particularly important when the block sample is known to be substantially warmer or cooler than the test room.

NOTE.—Block samples may be warmer than normal air in the test room because of recent exposure to drying kiln, autoclave, or sunshine. They may also be cooler if taken from the stockpile in cool weather. *Never attempt to make relative humidity determinations upon block which are obviously damp or are warmer or cooler than the air of the test room.* Warm block may exude moisture which will condense upon the cooler surfaces of the test container and hygrometer and give an erroneous indication of the moisture condition of the block. Hence, as a general precaution, the block should have ample opportunity to cool (or warm) to the temperature of the test room and apparatus before removal from the storage container for test.

Determination of Moisture Condition.—Remove the full-size block specimen from the vaportight storage container and score it on two faces with a cold chisel and hammer so it will break into two approximately equal portions or half block as shown in views (*a*) and (*b*) of Figs. 7 and 8. Clearly mark one half (or the larger portion if not of equal size) with the letter "B" and with the same test number used for the remaining portion.



Data Sheet No. 4

DATA ON TEST FOR MOISTURE-HUMIDITY CONDITION OF BLOCK

Test No. 7 By Don Thomas At Atlas Lime Co., El Paso, Texas
Date May 20, 1952
Observers O.H. Henderson, Ervin Hahn, Harry Frank, Dick Ballard
Hygrometer: Type Serdex Serial No. 3927

Notes on Block

Block No. 2 Nominal Size 8 x 8 x 16 No. and Shape of Cores 3 Aggregate Volc. Cinders
Method of Curing: High Temp. ✓ ? High Pressure ? Other ?
Method of Drying: In outside air 3 hrs. ? Under roof — ? for — days
: In drying kiln ? for hrs. at oF.
: In high pressure cylinder ? With vacuum ?
Before breaking, does block appear dry Yes ? or damp No ?

Note: At this point score and break block into two approximately equal portions or half block. Clearly mark one half (or the larger portion if not of equal size) with the letter B and the above test number, then store in a vaportight container or wrap in a plastic sheet to prevent moisture change until later test. Next break remaining portion into small pieces or lumps so that the largest dimension of any lump will range between 3/4 and 2 inches. Examine face shells and webs for any discoloration as they are broken.

Do freshly broken surfaces show a discoloration which appears to be dampness
in face shells Yes ? in webs Yes ?

Screen lumps on 3/4-in. mesh sieve to remove all dust and particles, place lumps in expanded metal pail, and then lower pail concentrically within the container of apparatus.

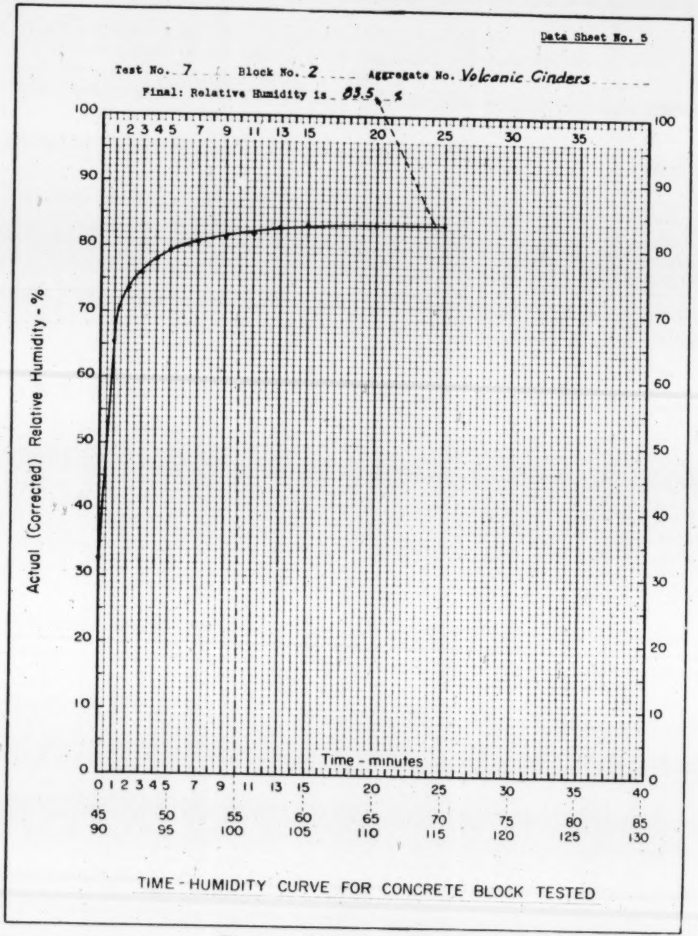
Time, Relative Humidity and Temperature Date of Test

Test started at 8:32 AM (give hour and minutes)

Time, min.	Relative Humidity Indicated, %	Relative Humidity Actual,** %	Temperature In Can, oF.	Temperature In Room, oF.	Time, min.	Relative Humidity Indicated, %	Relative Humidity Actual,** %	Temperature In Can, oF.	Temperature In Room, oF.
0	35.0	32.5	75.5	76.0	40				
1	63.5	65.5			45				
2	70.0	73.5			50				
3	72.0	76.0			55				
4	73.5	78.0			60				
5	74.6	79.5	75.0	77.5	65				
7	75.7	80.5			70				
9	76.3	81.5			75				
11	76.9	82.0	75.5	77.5	80				
13	77.5	83.0			85				
15	78.0	83.5	76.0	77.0	90				
20	78.5	83.5	76.0	----	100				
25	78.5	83.5	76.8	77.0	110				
30					120				
35					130				

*Values at zero time are the relative humidity and temperature of room air indicated by the hygrometer and thermometer in the cover just before it was placed on the container.
**This is the correct value of relative humidity for each indicated value obtained from the calibration curve for the hygrometer used.

Data Sheet No. 4



Data Sheet No. 5

Test No. 7 Block No. 2 Aggregate No. Volcanic Cinders
Final: Relative Humidity is 83.5 %

TIME - HUMIDITY CURVE FOR CONCRETE BLOCK TESTED

Data Sheet No. 5

Then store in a vaportight container or wrap in a plastic sheet to prevent moisture change until test.

NOTE.—Portion B provides a specinem for either a rate of absorption test, a second relative humidity test, or a total absorption test, if desired.

Break the remaining portion into small pieces or lumps with a hammer and cold chisel, as shown in Figs. 7(*c*) and (*d*), so that the largest dimension of any lump will range between ¾ and 2 in. As the face shells and webs are broken, note and record (in the space provided on the data sheet No. 4) if any of the freshly broken surfaces of the lumps show a discoloration which appears to be dampness in either the face shells or webs, or both.

NOTE.—Extensive observations and tests have indicated that when the freshly broken surfaces of a block show a discoloration which appears to be dampness the concrete is likely to contain more moisture than normal for average outdoor relative humidities in practically all sections of the United States. However, lack of discoloration does not necessarily imply that the moisture in the block is not above normal. When used with judgment and discretion, observations on discoloration can be helpful if it is reasonably certain that the discoloration is due to the presence of moisture.

Remove all dust and particles by vigorously screening the lumps over a 12-in. diameter sieve having ¾-in. square meshes, place the screened lumps in the expanded metal pail, and lower the pail concentrically within the container as shown in Figs. 7(*e*) and (*f*).

On data sheet No. 4, record at 0 min the reading of relative humidity and temperature of room air indicated by the hygrometer and thermometer in the cover just before it is placed on the container. Also record the temperature of the regular room air thermometer suspended near the apparatus. All hygrometer readings should be read to the *nearest half percentage point* of the humidity scale and all temperature readings to the *nearest degree Fahrenheit.*

Place the cover on the container and seal with the lever-locking ring. Wind the timer and set at 0, then start the timer and plug in the blower motor. The apparatus will appear the same as in Fig. 6(*e*) during the calibration test. Make a series of spot readings of relative humidity within the container at the exact time in minutes listed on data sheet No. 4. Record these in column marked "Indicated Relative Humidity." Temperatures within the container and of room air should be made at approximately 5-min intervals and recorded in the proper columns of the table.

As soon as time permits during the progress of the test, use the calibration curve for the hygrometer on data sheet No. 3 to obtain the correct or actual value for each indicated value of relative humidity and record it in the column marked "Actual Relative Humidity" on data sheet No. 4 Then use data sheet No. 5 to plot each value of *actual* relative humidity against the corresponding time in minutes to obtain the time-humidity curve for the concrete block tested.

This curve should establish the trend of the relative humidity readings with time during the first 20-min period. If the curve has definitely leveled off to a "constant" value (that is, within one percentage point of humidity) for a period of 10 min, the test should be discontinued. Otherwise, readings should be continued at 5-min intervals (as listed on data sheet No. 4) until the curve has definitely leveled off. However, if the curve has not leveled off at the 60-min period and indicates a definite trend toward further change, readings should be discontinued and the test stopped.

Such a delay in leveling off usually indicates a nonuniform moisture condition in the block from which the lumps were obtained.[13] In such cases the relative humidity at 60 min becomes the significant relative humidity, indicating the desired moisture condition of the concrete and should be recorded as being the *final* relative humidity of the concrete. In all other cases the final relative humidity is that indicated by the time-humidity curve where it has leveled off to a constant value. Record the final value of relative humidity in the space provided at the top of data sheet No. 5.

At the conclusion of the test, stop the timer, unplug the blower, remove the cover and pail of lumps from the container, wipe the inside of the container free of dust, and seal the cover to protect the apparatus until the next test. The apparatus should be handled with care at all times to avoid damaging the hygrometer.

The test procedure outlined may be used in two ways:

(*a*) *As an acceptance test* that will indicate whether or not a given lot of block meet the degree of dryness required by specifications for a specific purpose.

(*b*) *As a plant inspection test* that will indicate to the block manufacturer the moisture condition of different lots of block at the plant so he will know when they are dry enough or what further drying is required for a specific purpose.

The time-humidity curve is always useful in borderline cases, that is, where there may be some question whether or not the desired degree of dryness has been attained. In other cases it is useful in indicating at very early stages of the test, sometimes within 5 min or less, that the block contains more moisture or less moisture than desired. When such early readings already indicate relative humidity values which are higher or lower than desired, later readings will be still higher or lower, respectively, and judgment must be used in deciding whether the test should be continued or terminated. This depends on the purpose of the test.

Acknowledgment:

The author acknowledges his appreciation and gratitude to several individuals whom he consulted during the development of the test procedure and later during the preparation and review of this paper. Among these are Harold H. Steinour, William Lerch, Treval C. Powers, Hubert Woods, Douglas McHenry, Clifton C. Carlson, Joseph J. Shideler, George Verbeck, and H. F. Gonnerman (now retired), all of the Research and Development Laboratories of the Portland Cement Assn.; R. E. Copeland of the National Concrete Masonry Assn.; and W. G. Brombacher and Arnold Wexler of the Mechanical Instruments Section, National Bureau of Standards.

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[13] If, for instance, some portions of a block are "air-dry" but other portions are damp enough to contain free water, the pieces into which the block are broken for test will consist of a mixture of "dry" and "damp" lumps of concrete. The damp lumps lose moisture and give this up to the air in the container, and this air in turn transfers its moisture to the dry lumps. This moisture transfer from damp to dry lumps takes time and may not be completed in 24 hr or more. However, tests with lumps of known and varying moisture condition have shown that a fair and significant indication of moisture condition, as it affects the potential shrinkage and swelling characteristics of the concrete, may be provided at the end of 60 min of test.

It is also possible for some portions of a block to be damper than others but not damp enough to contain free water. In other words, some portions are at a higher relative humidity condition than other portions. Here again the broken pieces of concrete will be a mixture of "dry" and "damp" lumps, but since no free water is present, the total amount of moisture interchange is small in this case, and the time-humidity curve rapidly levels off to final value for the mixture.

APPENDIX I

DETERMINATION OF MOISTURE CONDITION OF HARDENED CONCRETE AT SURFACE AND INTERIOR OF LARGE SPECIMENS

In concrete research and in field practice, it is often desirable to have definite information on the moisture condition of concrete in walls, floors, or other large members of a building. For instance, in tests of the thermal conductivity of solid concrete slabs (as well as other materials and assemblies), it is well known that the thermal conductivity increases or decreases substantially with increase or decrease in moisture content. Hence, it is desirable to know the moisture condition of the slab specimens not only at the surface but also at the interior before tests for thermal conductivity are started and again after they are completed. Knowledge of the moisture content of concrete slabs and other members is also important in the field of fire tests; in determining the effectiveness of vapor barriers on wall or floor slabs; and in determining when a concrete floor slab is dry enough for the application of paint or covering with rugs, asphalt or rubber tile, linoleum, wood flooring, etc. Such information can be obtained by the methods outlined below.

The diagrams of Fig. 9 illustrate several ways in which the moisture condition of large concrete specimens may be determined from measurements of relative humidity without enclosing them completely in a sealed container as was done with the small lumps of broken concrete block illustrated in Fig. 3. In the case of a wall panel or other large specimen, only a portion of the concrete surface needs to be sealed off from the surrounding air.

Diagrams (*a*) and (*b*) of Fig. 9 show how this can be done by clamping a hollow metal cover of any convenient size over the concrete surface, a tight joint being obtained at the contact edges by means of a sponge rubber gasket or other effective sealing agent. The relative humidity of the air within the enclosure will come to equilibrium with the moisture in the concrete and indicate the approximate moisture condition of the concrete at or near the surface of the enclosed area.

If it is desired to determine the moisture condition of the interior of the concrete as well as near the surface, this can be done as illustrated in diagrams (*c*), (*d*), and (*e*) of Fig. 9 by measuring the relative humidity in sealed cavities or holes of convenient diameter and depth provided in the concrete for this purpose. The relative humidity at any given station *X*, *Y*, or *Z* can be indicated by a small electric sensing element of proper humidity range.[14] Diagrams (*f*) and (*g*) and the notes accompanying Fig. 9 illustrate how holes of various depths may be cast into the concrete around metal sleeves and how the sensing element is sealed within a small enclosure to indicate the relative humidity of the exposed concrete at the bottom of the hole. It appears possible to use approximately the same technique with drilled holes as with cast holes.

Obviously, whether holes are cast or drilled into the concrete, the concrete technician must work out the detailed procedure and apparatus necessary well in advance to prevent any unnatural moisture change in the concrete around the holes before and during moisture determinations. The above methods using cast holes have been used with good results for determining the moisture condition of concrete wall and floor slabs during the seasoning period before exposure to fire endurance tests at Underwriters' Laboratories, Chicago, Ill. Some results of humidity readings in concrete are illustrated in Fig. 10 and accompanying notes.

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[14] The sensing element of the Aminco-Dunmore electric hygrometer is based on the change in electrical resistance of a hygroscopic chemical film with changes in relative humidity (**3**).

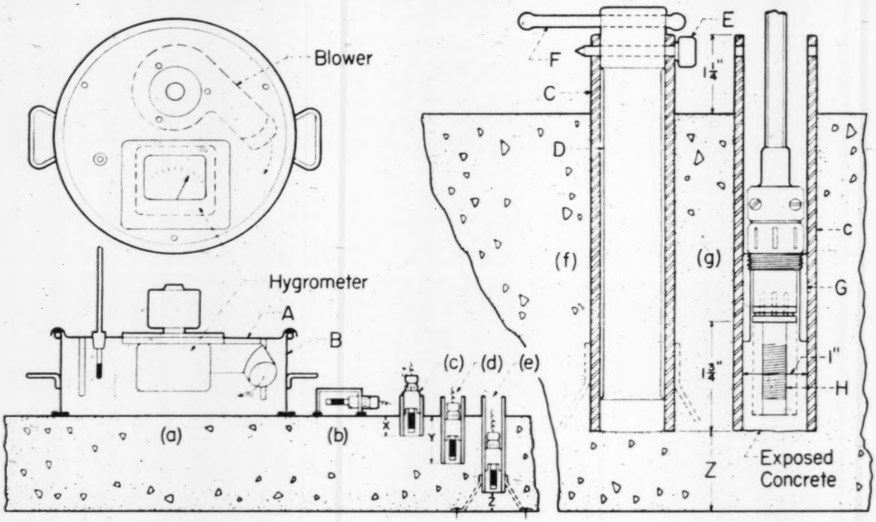

Fig. 9.—Diagrams Illustrating Several Ways for Determining the Relative Humidity of Hardened Concrete at the Surface and Interior of Large Specimens.

In diagram (*a*) the cover *A* with hygrometer and blower is the same assembly as illustrated in Fig. 3 except that it is now used to cover a ring *B* instead of the metal container for testing lumps of concrete block. The ring *B* is 13⅝ in. in diameter and can be made by cutting off the lower two thirds of the metal container in Fig. 3 so that the inside height of the enclosure will be about 5 in.—enough to provide good clearance and air circulation. The lower edge of the ring should be turned true and be slightly rounded so that it will make a good seal with the sponge rubber gasket. The hygrometer under cover *A* may be either the Serdex mechanical type or the Aminco-Dunmore electrical type. Both instruments have advantages and disadvantages which may or may not be important, depending on the conditions under which they are used.

In diagram (*b*) the metal cover provides an enclosure 2½ in. square and 1¼ in. high for housing an Aminco-Dunmore electric sensing element of the same type as shown in greater detail in diagram (*g*). This element screws into a hole at one end of the cover and is connected by a cable to the humidity indicator.

In diagram (*f*) concrete is cast around a sleeve *C* of cold-drawn seamless tubing 1¼ in. OD by 1 in. ID. The sleeve is held so that the relative humidity of the concrete may be measured at the distance *Z* from one face of the slab. The sleeve is sealed at its lower and upper ends by a removable metal plug or piston *D*. The ends of this plug are made about 0.003 in. less in diameter than the inside diameter of the sleeve. With this amount of clearance, the plug can be moved into and out of the sleeve without difficulty, and yet seal the lower end of the sleeve during casting of the concrete and prevent moisture loss from the concrete at the bottom of the hole between relative humidity readings. The lower end of the plug is held flush with the end of the sleeve by means of the removable pin *E*. The upper end of the plug is provided with a lever *F* with which the plug may be turned as it is being removed from the hole.

Diagram (*g*) shows how a short movable piston *G* of cold-drawn seamless tubing is screwed to the threaded section of the socket of the electric sensing element *H*. When relative humidity measurements are to be made, the plug *D* is removed, and the sensing element with attached piston is inserted into sleeve *C* until the sensing element touches the exposed concrete at the bottom of the hole. The assembly is then withdrawn about ¼ in. so that both the concrete surface and sensing element are fully exposed to the air within the 1-in. diameter by 1¾ in. long enclosure sealed off by the piston. Of course, the piston must move freely within the sleeve, yet prevent significant leakage of vapor from the enclosure during readings of relative humidity. Hence, the piston diameter is made about 0.003 in. less than the inside diameter of the sleeve.

Although cast holes are preferable, there may be instances when drilled holes must be used. Obviously, these holes should be drilled with the least development of heat or moisture change in the concrete. It appears that the 1¼-in. straight round holes needed for this purpose may be readily obtained with the Tilden Rotary Koncrete Core Drill Bit driven by a conventional ½-in. "heavy duty" or ¾-in. "medium duty" drill Motor operating at a speed of 300 to 500 rpm. The walls of the drilled holes should be lined with metal sleeves carefully sealed into position so that only the concrete surface at the bottom of the hole is exposed during relative humidity measurements. Of course, the sealing material used should not contain water and should be otherwise suitable for this purpose.

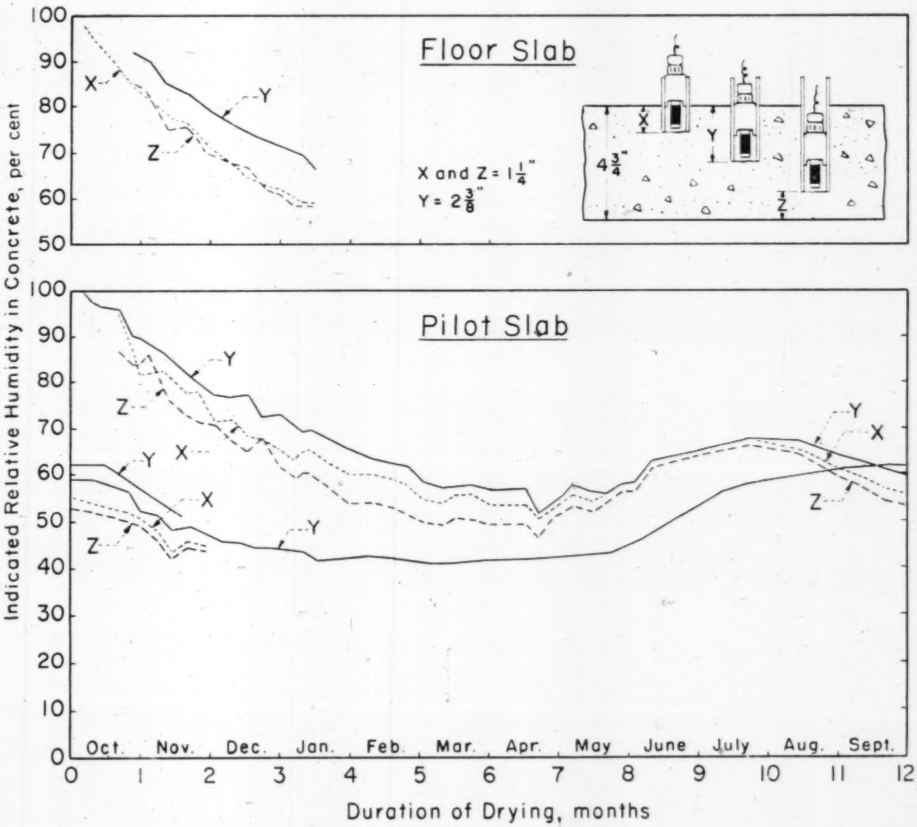

FIG. 10.—Changes in Relative Humidity in $4\frac{3}{4}$-in. Slabs of Sand and Gravel Concrete During Storage in Air of Laboratory.

NOTES:

Data obtained by J. P. Thompson, Portland Cement Assn., on floor slabs prior to fire exposure at Underwriters' Laboratories.

The upper diagram gives results with a full-size 14 by 18-ft floor slab specimen, $4\frac{3}{4}$ in. thick, cast on October 2, 1952. Relative humidity readings were terminated at $3\frac{1}{2}$ months to conduct a standard fire endurance test on this specimen.

The lower diagram gives the results with a small 12 by 18-in. pilot slab specimen of the same thickness and from the same concrete as the large slab exposed to fire. The four edges of the pilot specimen were carefully sealed with a rosin-paraffin mixture to confine moisture loss to the two opposite faces. Readings were continued over a period of over 2 yr, and the graphs clearly illustrate the response of the concrete to seasonal changes in relative humidity of air in a heated non-air-conditioned building in Chicago.

APPENDIX II

DETERMINATION OF MOISTURE CONDITION OF HARDENED CONCRETE WITH HUMIDITY-SENSITIVE COLOR INDICATORS

Besides the Serdex mechanical hygrometer (based on the change of dimension of goldbeater's skin) and the Aminco-Dunmore electric hygrometer (based on the change in electric resistance of a hygroscopic chemical film), the indication of relative humidity by chemical means, such as by change in color, appears to offer considerable promise in the determination of the moisture condition of concrete (**13, 14**).

For example, a small paper card has been developed containing a series of seven circles each ⅝ in. in diameter, impregnated with a chemical which changes color from blue to pink as the humidity increases and from pink to blue as the humidity decreases. By progressively varying the concentration of the impregnating chemical from circle to circle in this series, each circle can be made to change color at a given level of humidity. The circles on this card are arranged to indicate relative humidities of 10, 20, 30, 40, 50, 60, and 70 per cent. It may be possible to develop similar color indicators for relative humidities of 80 and 90 per cent and for humidity intervals of 5 per cent.

Humidity-sensitive cards or papers of this type can be made to occupy relatively small areas and volumes, and hence can be used to indicate relative humidity within enclosures either at the surface of concrete, in holes in the concrete, or in vaportight containers in which concrete specimens are placed. Since these sensitive cards are also relatively cheap, they give promise of becoming quite useful, particularly if they are developed to give reliable indications under various service conditions. Color indicators are briefly discussed under "Chemical Methods" on page 11 of reference (**6**).

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DISCUSSION

MR. BRYANT MATHER[1].—I would like to ask Mr. Menzel if he has tested or considered any other devices that have been proposed for embedment in concrete to obtain information on moisture content. I have reference particularly to such devices as the Huggenberger Telehumeter. We have been unable to determine that any tests on it have been made in this country. It operates on the basis of an electrolyte solution, with a membrane that causes water either to be added to or lost from the electrolyte, thereby changing its electrical conductivity to maintain an equilibrium with the available moisture in the surrounding concrete. This is an approach that has been particularly recommended for determinations made in massive structures at large distances remote from the observing station.

MR. C. A. MENZEL (*author*).—I am not acquainted with the device, I am sorry to say, but offhand I would not expect it to perform as rapidly as the Aminco-Dunmore electric sensing element does. The response to ambient relative humidity is fairly rapid with that kind of a sensing element and it does indicate the moisture condition of a material in terms of relative humidity when used as described in the paper. I am pleased to know about the telehumeter because I am trying to get all the information possible, which will help us to determine the moisture condition of hardened concrete.

MR. MATHER.—The telehumeter was devised by E. Brasey of the University of Fribourg, Switzerland, and is described in Brochure No. 82 issued by A. U. Huggenberger, Zurich. It is also described in Huggenberger's book *Talsperren Messtecknik* (Springer Verlag, 1951). Results obtained with its use are presented and discussed by Marius Besson in "Sechage et Vieillissement du Beton dans les Barrages," Schweizerische *Bauzeitung* (Vol. 72, No. 26, pp. 371–375, June 26, 1954) (*Ceramic Abstracts*, February 1955, p. 25). A translation of Besson's paper is on file at the Waterways Experiment Station.

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[1] Engineer, Concrete Division, Waterways Experiment Station, Jackson, Miss.

OSMOTIC STUDIES AND HYPOTHESIS CONCERNING ALKALI-AGGREGATE REACTION*

By George Verbeck[1] and Charles Gramlich[2]

Since Stanton's discovery of the alkali-aggregate reaction (**1**, **2**),[3] a number of investigators have attempted to isolate and study the factors controlling the "pattern cracking and abnormal expansion" of concrete frequently associated with cements of high alkali content and certain types of siliceous aggregates. Hansen (**3**) has proposed an osmotic pressure hypothesis regarding expansion from the alkali-aggregate reaction and such osmotic pressures of high magnitude have been demonstrated (**4**). Various means have been used to prevent the expansion, including the elimination of the reactive aggregate, the limitation of alkali in cement, or the addition of certain pozzolanic materials (**5**). Recently some researches have indicated that the detrimental reaction, even in the presence of alkali and reactive aggregate, may perhaps be effectively inhibited by the addition of relatively small amounts of various other materials (**6**). Although substantial progress has been made in our understanding of the alkali-aggregate reaction, these advances have served to indicate that additional information regarding the nature of the chemical and physical mechanisms involved is necessary.

The reaction of certain types of siliceous aggregate in mortar or concrete with components of the cement may take one or more of a wide variety of forms, depending upon the prevailing conditions. For example, if alkali (potassium, sodium, oı lithium hydroxide) is absent during the reaction, some type of calcium silicate product may be formed; but if large concentrations of alkali are present and the calcium hydroxide is relatively unavailable, the reaction product will be predominantly of the alkali silicate type. The formation of calcium silicates would normally be considered as nondetrimental to the mortar or concrete, whereas internal formation of sufficient alkali silicates would ultimately result in expansion. Thus siliceous material can form, as extremes, either an innocuous calcium silicate type of product or a deleterious alkali silicate product in concrete. In reality, it would appear that the reaction product commonly produced is a mixture of both innocuous and deleterious products, or effectively has characteristics between the two extremes mentioned. The problem is to determine the importance of several factors upon the nature of the reaction product.

In addition, the physical characteristics of the reaction products may differ widely. In some instances, abnormal expansion occurs when the only visible apparent reaction products appear as relatively solid materials at the periphery of the aggregate; in others a soft gel-like material exudes throughout the specimen; and in still others no reaction products are visible although substantial expansion occurs (7, 8). Deleterious alkali silicate type products can normally occur in these various physical conditions, either as apparent solids, gels, or simply in solution (3), but all forms have in common the ability to imbibe water, increase in volume, and cause expansion. In the case of the solid or gel-like product, this ability may more precisely be considered as a swelling pressure, and in the case of the liquid solution as osmotic pressure, but in the gross aspect these tendencies are fundamentally similar (9). The exact physical condition of the alkali silicate type of product in each particular circumstance will apparently depend upon several factors, such as the amount of space, water, and alkali available to the product.

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* Presented at the Fifty-eighth Annual Meeting of the Society, June 26–July 1, 1955.

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[2] Formerly, Associate Research Chemist, Applied Research Section, Portland Cement Assn. At present, Technical Director, Chicago Apparatus Co., Chicago, Ill.

[3] The boldface numbers in parentheses refer to the list of references appended to this paper, see p. 1127.

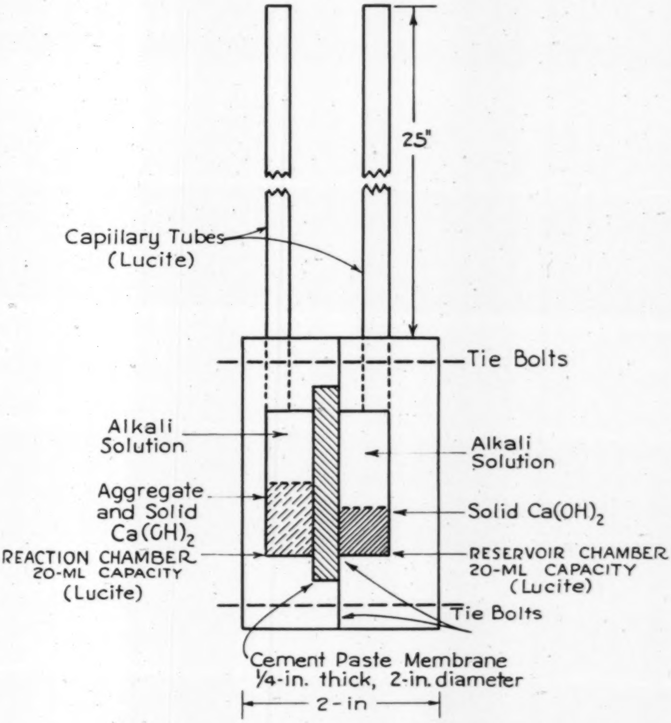
25"
Capillary Tubes (Lucite)
Tie Bolts
Alkali Solution
Alkali Solution
Aggregate and Solid Ca(OH)2
Solid Ca(OH)2
REACTION CHAMBER 20-ML CAPACITY (Lucite)
RESERVOIR CHAMBER 20-ML CAPACITY (Lucite)
Tie Bolts
Cement Paste Membrane ¼-in. thick, 2-in. diameter
2-in

FIG. 1.—Schematic Diagram of Osmotic Cell.

It appeared that certain features of the alkali-aggregate reaction could best be studied by means of an osmotic technique using a simplified system resembling, in essence, the physical and chemical situation within mortar or concrete. Separation of the physical components of the reaction permits the separate study of certain variables and the direct observation of some of the chemical and physical aspects of the reaction mechanism, thus avoiding interpretation in indirect terms such as "expansion" or "cracking," which in themselves involve a complexity of additional and important factors that might preferably be studied separately. The following discussion concerns studies of the alkali-aggregate reaction by means of such a simplified osmotic system.

EXPERIMENTAL PROCEDURE

The experimental procedure was devised so that the physical type of any deleterious reaction product formed would primarily be of the gel-like or solution type. Thus the amount of this deleterious product would be primarily reflected by the development of an osmotic pressure[4] between the solution surrounding the reaction zone and a reference solution.

The apparatus, Fig. 1, consists of two chambers separated by a membrane of neat cement paste. Aggregate, solid calcium hydroxide (minus No. 325 sieve), and alkali solution are placed in one chamber, thus simulating the zone at the surface of aggregate in concrete. This chamber is separated, as in concrete, by cement paste from the second chamber which provides, as in concrete, a reservoir for additional solid calcium hydroxide and the same alkali solution. Capillary tubes attached to each chamber permit the measurement of liquid movement from the reservoir chamber to the reaction chamber as required by the tendency of the reaction products to imbibe water and swell or develop osmotic pressures. This technique, using the apparatus which can for convenience be identified as an osmotic cell, permits the isolation and direct study of several variables including the effects of different alkalies, different alkali concentrations, paste permeability characteristics, aggregate particle size, lime inhibition, and temperature. Certain aspects of the results obtained and implications of such results will be considered separately and in detail in the following discussions.

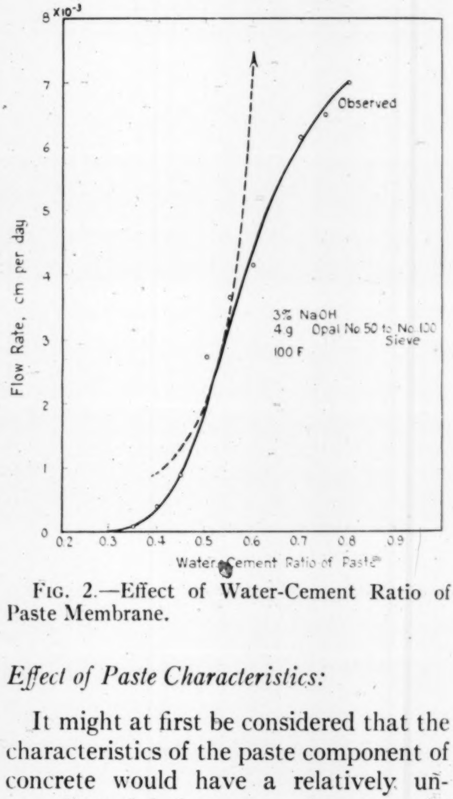

FIG. 2.—Effect of Water-Cement Ratio of Paste Membrane.

Effect of Paste Characteristics:

It might at first be considered that the characteristics of the paste component of concrete would have a relatively uncomplicated influence on the course of reaction and development of abnormal expansion. Consideration of the chemical and physical aspects of the reaction, however, reveals the multifold role of the cement paste.

The water-cement ratio and degree of hydration of the cement paste influence the concentration of alkali in the cement liquid within concrete; these effects on alkali concentration are in addition to those produced by different alkali contents of the original cement itself. The permeability of pastes to water may differ, hence causing variations in the rate at which water can be supplied to the reaction site; this results in variations in rate of expansion. Paste characteristics can also cause variations in the retention of or degree of impermeability of the membrane to the sodium silicate reaction products and hence alter the ability to expand, even though normally deleterious products are formed. Of course, the strength, elastic nature, and physical structure of the paste matrix of the concrete will also influence the apparent external expansion of a specimen, even for similar degrees of deleterious reaction.

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[4] The expression "osmotic pressure" will be used to represent the thermodynamic driving force existing between two solutions causing liquid to flow from one solution to the other through a membrane. This osmotic pressure is identical with the hydrostatic pressure that would be required to stop the flow of liquid through the membrane.

The effect of the permeability of the paste to water and reaction products has been experimentally separated from the effect of alkali concentration. A number of tests were conducted in which the only variable was the permeability of the neat cement paste membranes. To accomplish this, the membranes were prepared from cement paste of water-cement ratios from 0.35 to 0.80 by weight, the range normally encountered in mortar or concrete. All of the cement paste membranes were moist cured at 73 F for about one year before use. The results of these tests are shown in Fig. 2.

The rate of movement of liquid into the reaction chamber increased considerably as the water-cement ratio of the membrane was increased, reflecting in part the anticipated effect of water-cement ratio on water permeability alone. Since the same aggregate and concentration of alkali were used in all these tests, the reaction products and hence the osmotic pressure can be considered similar in each test. The rates of liquid movement therefore might be expected to reflect simply the various rates that would naturally result from differences in paste permeability, or resistance to liquid flow, for a constant pressure differential.

The dashed line shown in Fig. 2 represents the flow that might be expected in terms of published data concerning paste permeability as a function of water-cement ratio or porosity of the paste (10). This curve was drawn to coincide with the observed rate at one point, and it may be noted that the relationships are essentially similar in the lower range of water-cement ratios up to about 0.50 to 0.55. At water-cement ratios higher than about 0.55 to 0.60 by weight, the observed osmotic rates of flow depart significantly from this anticipated relationship and become considerably lower at water-cement ratios of about 0.80. This reduction in flow rate is believed to represent mainly a decrease in the osmotic pressure within the system due to counter diffusion of the sodium silicate product through the paste membrane and into the reservoir chamber. Indeed, considerable quantities of sodium silicate were observed exuding through the paste membranes having water-cement ratios above about 0.65 by weight.

It is obvious that, aside from the effect of paste characteristics (water-cement ratio, degree of hydration, etc.) on alkali concentration and paste strength, these paste characteristics can cause variations in the permeability of the paste to both water and silicate reaction products. These permeability effects oppose each other and can influence the reaction and its physical manifestations. Low water-cement ratios result in low permeability of the paste, which retards the movement of water to the reaction products and thereby reduces the rate of expansion. As the water-cement ratio is increased, the reaction products can imbibe water more rapidly and hence a more rapid expansion would be expected (perhaps ten- or a hundredfold), provided that other factors such as alkali concentration were equal. However, as the water-cement ratio of the paste membrane (or the concrete) is progressively increased, the paste becomes less capable of retaining fluid reaction products and hence of sustaining high osmotic pressures. At high water ratios, no expansion might be observed, even though extensive reaction had occurred. The results imply that there should exist some intermediate water-cement ratio of the paste at which a maximum rate of expansion or ultimate expansion should be observed as a function of this variable alone and that the observed expansions would be less for either lower or higher water-cement ratios. In addition to these effects, the water-cement ratio of the paste will also exert an important influence upon the alkali concentrations that are developed within the concrete.

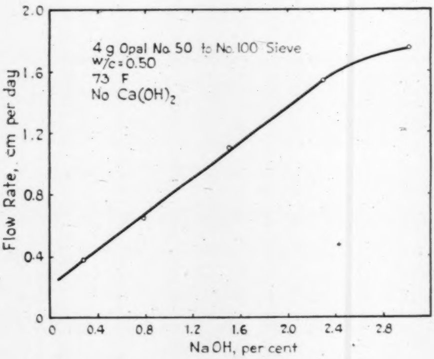

FIG. 3.—Effect of Alkali Concentration.

Effect of Alkali Concentration:

The results of previous research and pertinent published data indicate that the alkali content of the cement has a great effect upon the extent of the expansion observed in structures involving alkali-aggregate deterioration. The alkali concentration in the cement liquid in contact with the surface of aggregate in concrete will presumably be dependent upon the total amount of soluble alkali available from the cement and aggregate and upon the amount of water available for solution of the alkalies. The amount of water available is limited to a maximum directly related to the original water-cement ratio of the paste but may be less than this upper limit due to partial drying of the paste. Relatively high concentrations of alkali may be developed in paste or concrete, particularly with cements of high alkali content and in concretes that have low water-cement ratios or are subjected to drying.

It was apparent that both the nature and amount of reaction product could depend significantly upon the alkali concentration to which the reactive aggregate was exposed. This matter was investigated using sodium hydroxide over a range in concentrations but in the absence of any calcium hydroxide other than the small amount that might be leached from the neat cement paste membrane. The absence or presence of significant amounts of calcium hydroxide is of considerable importance to the nature of the reaction products formed and therefore to osmotic pressure developed. This will be discussed later in greater detail.

Figure 3 shows the effect of alkali concentration on the maximum flow rate observed, which represents the development of the maximum osmotic pressure in the cells. It is to be noted that there is an almost linear increase of flow rate with increasing alkali concentrations at the lower concentrations with a flattening of the curve as a high concentration is reached.

There are several points of interest regarding these particular experiments. The rate of flow observed is at any time a function of the solute concentration difference between the two chambers, which gives rise to the osmotic pressure. The concentration difference is dependent primarily upon the amount of reaction of sodium hydroxide with the siliceous opal.

The development of a constant rate of flow which persists for the duration of the experiment, generally 30 or more days, indicates that this concentration difference is established quite rapidly (between less than a day to eight days depending on the particular system), and the flow is then directly proportional to the initial concentration of sodium hydroxide. The inference is that the concentration difference, and consequently the osmotic pressure, arises from the reaction in the aggregate chamber of sodium hydroxide with silica, which is in excess. It follows that essentially all of the sodium hydroxide in the aggregate chamber can be assumed to be consumed by the reaction. Thus a steady rate is established and the reaction goes to completion during the initial stages of the experiment.

It is interesting in this regard to estimate the magnitude of the osmotic pressures of these various mixtures that produce the osmotic flow. These pressures can be calculated both from the rate of flow through the membrane in conjunction with the permeability of the membrane and also directly from the thermodynamic properties of the solutions. The latter calculation is based on the assumption that all of the sodium in the aggregate chamber has combined with silica to form an ionized product of the form $2Na^+ + SiO_3^{--}$ and that the membrane is impermeable to the SiO_3^{--}.

The results of such comparative calculations are shown in Table I. This satisfactory agreement tends to substantiate the significance of observed flow rate as a measure of the estimated osmotic pressure and degree of reaction of soda and silica. This quantitative verification of the significance of the flow rates observed in the osmotic cells permitted the separate comparison of the degrees or rates of reaction of the different alkalies—potassium, sodium, and lithium.

TABLE I.—COMPARISON OF PRESSURES CALCULATED FROM CHEMICAL CONCENTRATIONS AND OBSERVED FLOW RATES.

	NaOH Concentration, per cent by Weight	
	1.50	3.00
Calculated osmotic pressure,[a] psi	66.2	132.5
Pressure calculated from observed flow,[b] psi	66.7	106.5

[a] The calculation of the potential osmotic pressure was made assuming complete reaction of sodium hydroxide and assuming that the limiting law was applicable:

$$P_{osm} = RTC/M$$

where:
T = the absolute temperature in deg Kelvin,
P_{osm} = osmotic pressure in psi,
R = gas constant,
C = concentration in grams per liter, and
M = molecular weight.

[b] Pressures calculated from observed flow rates were based on the assumption that Darcy's law applied:

$$\frac{dq}{dT}\frac{1}{A} = \frac{K_2 \eta P'}{L}$$

where:
dq/dT = rate of volume efflux, ml per sec,
A = area of membrane, sq cm,
L = thickness of membrane, cm,
P' = pressure difference across membrane, dyne per sq cm,
η = viscosity of solution, dyne-sec per sq cm, and
K_2 = permeability coefficient, sq cm.

The permeability coefficient used (11.8×10^{-17} sq cm) was calculated on the basis of the most recent data available concerning the effect of cement composition, nonevaporable water, and water-cement ratio.

Comparison of Different Alkalies:

Tests were made to compare the reaction of different alkalies in the osmotic pressure cells in order to determine whether the type of reaction is the same for the different alkalies and whether they possess any different characteristics. Although lithium is not a usual constituent of cement, it appeared advantageous to determine if lithium hydroxide differed from potassium or sodium hydroxide in the type of reaction products formed, particularly in view of the observations of McCoy and Caldwell (6) concerning the inhibiting effects of lithium compounds on the expansion of mortar bars due to the alkali-aggregate reaction. Accordingly, comparative tests were made, using the osmotic cells, in which only the nature and concentration of the alkali were varied.

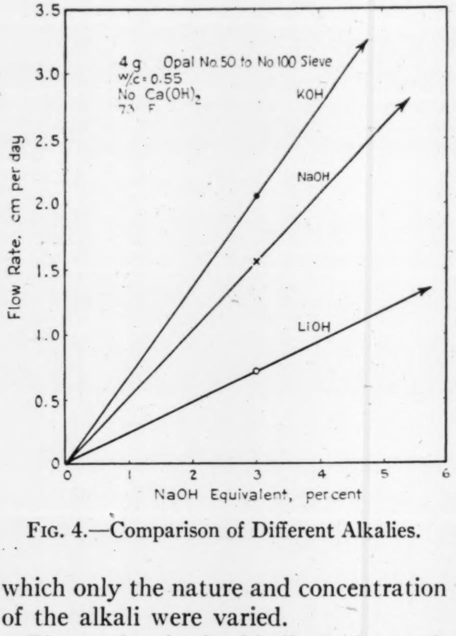

FIG. 4.—Comparison of Different Alkalies.

The results obtained indicate that each of the three alkalies, potassium, sodium, and lithium, will react with silica in the absence of lime to form reaction products that develop osmotic pressure. Hence, the inhibiting effect of lithium is not directly accountable to a different nature of its reaction products with silica. Just as the rate of osmotic flow at a particular time can be taken as a measure of the amount of deleterious product formed, the rate change or derivative of this flow can be taken as a measure of the rate of reaction of the alkali with the silica in the cells. An approximate index of the rate of reaction can be obtained by comparing the slopes of the chords (from the origin) of the volume-time relationships obtained at early ages for the different alkalies rather than the maximum linear slope used for estimating the amount of reaction products as used in the construction of Fig. 3.

A comparison is made in Fig. 4 of the reaction rates of the three alkalies, assuming a linear function of concentration. It indicates that the relative order of activity of the alkalies as indicated by fluid flow is potassium hydroxide with the highest activity followed by sodium hydroxide, with lithium hydroxide showing the lowest activity. This order of "activity" is contrary to the order of activity that might be estimated from consideration of the standard electromotive series or the atomic weights of the particular alkalies. For some reason, lithium is less aggressive or produces less flow than does sodium or potassium. This is an important observation that will subsequently be discussed. It is believed that the observed results may be directly related to either the lower permeability of the cement paste membrane to lithium ion or to the lower mobility of lithium ion in aqueous solution as compared to sodium and potassium. It is believed either of these phenomena could in turn be due to a parent phenomenon of "hydration" of ions in

TABLE II.—COMPARISON OF OBSERVED OSMOTIC FLOW RATES AND HYDRATION VALUES (**11**, **12**) FOR VARIOUS IONS.

Alkali Hydroxide	Average Rate of Flow to 7 Days, cm per day per 1 per cent NaOH Equivalent	Average Number of H_2O Molecules per Ion
Potassium........	0.70	5.4
Sodium..........	0.53	8.4
Lithium..........	0.24	14.0
Calcium.........	...	24.0

aqueous solution. This "hydration," being the development of a sphere of water molecules around the particular ions, effectively increases the gross size or sphere of influence of the ion and decreases its mobility. Some information in this regard is shown in Table II.

It may be noted that the observed measure of reactivity is closely associated with published data concerning ion hydration and mobility in aqueous solution, and at present this information appears to provide a reasonable explanation for the otherwise anomalous order of reactivity of the different alkalies. It would appear that, although lithium ion might be expected to be most aggressive toward silica, the effective size of the lithium ion in aqueous solution is increased by "hydration" to the extent that its size is considerably larger than even the potassium ion and hence cannot diffuse to or attack the silica surface with the rapidity of the potassium ion. Whether this effect in concrete is more or less important than the presumably lower effective paste permeability and hence lower flow rates through the paste membrane to the larger lithium ion, as compared to the sodium and potassium ions, will require further detailed study. The influence of alkali mobility on the nature of the reaction products will become apparent with their comparison in the presence of calcium hydroxide.

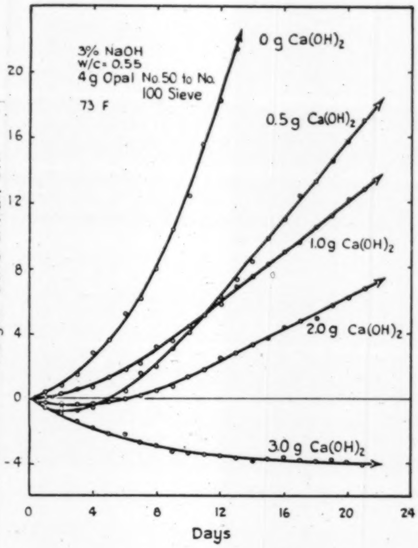

Fig. 5.—Effect of Calcium Hydroxide on Observed Height Differentials.

Effect of Calcium Hydroxide:

One of the anomalies found in studies of the alkali-aggregate reaction which has been most difficult to explain is the observation that an alkali silicate gel can apparently exist in a system that contains a large quantity of supposedly available calcium hydroxide, even though only a small fraction of the calcium hydroxide at any time may be in the aqueous solution. It would seem that the calcium hydroxide present in cement paste would react with any alkali silicate produced by the alkali-aggregate reaction, forming innocuous nonswelling calcium silicate or calcium alkali silicate product rather than the swelling-type alkali silicate gel.

Kalousek (13) has reported solubility data in the system of soda-lime-silica-water at 25 C which shows that the solubility of calcium hydroxide decreases very abruptly with increasing sodium hydroxide concentration. This solubility effect could perhaps explain the initial lack of formation of the calcium silicate type of product, but as the alkali concentration in the cement solution decreases due to reaction of alkali with silica, the solubility of the calcium hydroxide would increase and thus become more readily available for reaction. This mechanism is difficult to accept since abnormal expansion develops in structures after long periods of time and in many cases gives the appearance of progressing with additional time.

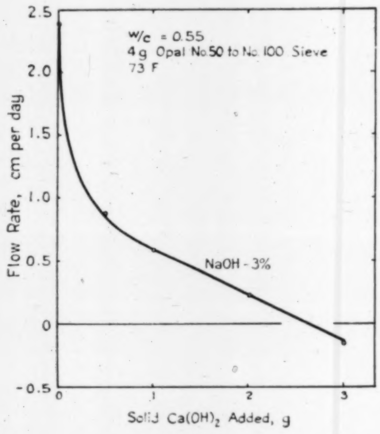

FIG. 6.—Effect of Calcium Hydroxide on Maximum Flow Rate.

TABLE III.—ANALYSIS OF SOLUTIONS OF SODIUM HYDROXIDE CONTAINING DIFFERENT AMOUNTS OF SOLID CALCIUM HYDROXIDE.

Solid calcium hydroxide per 100 ml sodium hydroxide solution, g	0	1.76	3.48	6.95	10.5	13.9
Sodium hydroxide, g per 100 ml after 14 days[a]	3.00	2.95	2.93	2.98	2.94	2.94

[a] Limits of precision of analysis are ±0.06 g per 100 ml.

The effect of calcium hydroxide upon the reaction was studied in the osmotic cells by adding equal quantities of solid calcium hydroxide to both chambers of the cells. Figure 5 shows a family of curves of liquid height differentials which are a measure of the gross liquid transfer between the two chambers as a function of time for cells containing different added quantities of solid calcium hydroxide. The difference in the curves as a function of the amount of calcium hydroxide is readily apparent. Figure 6 is the composite of this family of curves that is obtained from the maximum flow rate for the different quantities of calcium hydroxide. The major point of interest of these observations is that the flow rate, for a given set of experimental conditions, decreased markedly with increases in the amount of solid calcium hydroxide and actually reversed when 3 g of calcium hydroxide were used. It should be kept in mind that in most cases the quantity of calcium hydroxide present was quite large, particularly with reference to its low solubility in 3 per cent sodium hydroxide solution, and that for some reason, the calcium hydroxide was not available for inhibition of the deleterious reaction until extremely large excesses were present.

To preclude the possibility that this phenomenon was due to an effective decrease in the sodium hydroxide concentration because of adsorption on the calcium hydroxide, thus giving an effective decrease in the rate of reaction, a study of the adsorption of sodium hydroxide on solid calcium hydroxide was undertaken. Table III includes the results of chemical analyses of sodium hydroxide solutions in contact with varying quantities of solid calcium hydroxide for a two-week period at 25 C. No significant decrease in sodium ion concentration is indicated by these results. This observation was also confirmed by special tests in the osmotic cells.

These results led to considerable conjecture as to the possible benefits to the reaction of, for example, 3 g of solid calcium hydroxide compared with 2 g of solid calcium hydroxide, where both were believed to be in excess of reaction and solubility requirements. In an effort to explain this effect, two osmotic cells were prepared with exactly the same quantities of No. 50 to No. 100-sieve opal, calcium hydroxide, and identical solutions of 3 per cent sodium hydroxide. They differed only in the manner in which the aggregate and calcium hydroxide were distributed in the reaction chamber of the cells. In one cell, the calcium hydroxide was placed in a layer on top of the aggregate with as little intermixing as was possible. The other cell contained thoroughly mixed aggregate and calcium hydroxide. The observed height differentials of these cells after various reaction times are shown in Fig. 7. It may be observed that the flow rate for the "stratified" cell is considerably greater than that obtained for the "intermixed" cell, again indicating that it is not primarily a matter of the quantity of calcium hydroxide that is present in the cell but rather a matter of its location or availability to the silica surface.

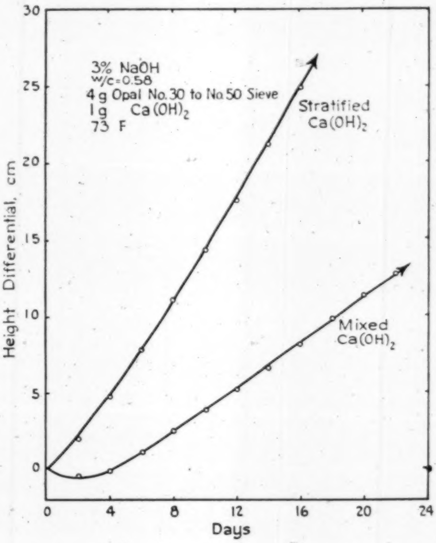

FIG. 7.—Comparison of Results Obtained with Stratified and Intermixed Calcium Hydroxide.

These tests are significant in that they indicate that variations in the amount of calcium hydroxide present profoundly influence the course of reaction of silica as to whether greater or lesser amounts of the deleterious product are formed. Sufficient calcium hydroxide can apparently completely inhibit the formation of the deleterious sodium silicate type of product. This inhibition would not appear to be related to the low solubility of calcium hydroxide in alkali solution directly, for sufficient quantities were available at all times to sustain saturation for a considerable amount of reaction. If rate of solution of calcium hydroxide was the limiting mechanism—requiring the large excesses—then the stratified and unstratified cell tests should have produced essentially similar results, since the same area of calcium hydroxide surface was available for dissolution in each case. The adsorption of alkali by calcium hydroxide does not appear to be a factor; rather the proximity of the calcium hydroxide and silica appears to be of primary importance. For some reason, the calcium hydroxide must be in very close proximity to the reacting surface in order to produce the innocuous calcium silicate type of product rather than the deleterious sodium silicate product.

This implies that the addition of calcium hydroxide or calcium ion as calcium chloride to concrete during mixing would not materially improve the availability of calcium hydroxide to the reacting surface. It is probable that this lack of availability of calcium hydroxide is due primarily, in these tests, to the relatively low mobility of calcium ion or hydroxide in aqueous solution as compared to the alkali ions.

One may then hypothesize that the course of reaction of calcium hydroxide, alkali, and silica proceeds on a competitive basis at the surface of the reactive aggregate. The nature of the products, whether deleterious or innocuous, will depend upon the relative availabilities of alkali and calcium hydroxide at the silica surface. If the alkali availability, a combination of concentration and mobility, is high compared to the calcium hydroxide availability, also a function of concentration or solubility and mobility, then an alkali silicate type of product is formed. If the calcium hydroxide availability is high compared to the alkali availability, then the innocuous calcium silicate or calcium alkali silicate type of product is formed. In reality, the results can be interpreted to indicate that mixtures of the two types of products are generally obtained, the relative quantities depending on the overall relative availabilities of the alkali and calcium hydroxide. Practically all of the data obtained in this study and data reported elsewhere can be interpreted in terms of this competitive reaction hypothesis and the low mobility of calcium hydroxide in aqueous solution and through neat cement pastes.

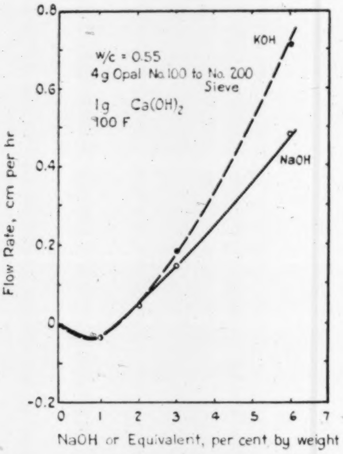

FIG. 8.—Comparison of Sodium Hydroxide and Potassium Hydroxide Using a Constant Amount of Calcium Hydroxide.

These results also indicate that in mortar or concrete a deleterious reaction will occur only when the alkali concentration exceeds some minimum concentration. This concept has, of course, been recognized in construction practice and has been expressed in many cases by limitations on the maximum alkali content of the cement. The occurrence of a threshold concentration, in principle, was directly verified by osmotic cell tests. The results of such tests are shown in Fig. 8. It may be noted that under the specific conditions of test an alkali solution concentration of about $1\frac{1}{2}$ per cent was required to produce a positive osmotic pressure. Obviously this threshold concentration for each particular case will be a function of several factors, such as the quantity and fineness of the reactive aggregate, etc., but the concept and its general application to natural aggregates is believed to be substantially correct.

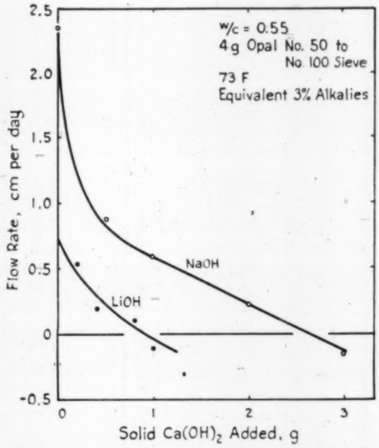

FIG. 9.—Comparison of Effect of Solid Calcium Hydroxide on Sodium Hydroxide and Lithium Hydroxide Flow Rates.

It is of interest to compare the results obtained with lithium hydroxide and sodium hydroxide in systems containing various amounts of calcium hydroxide. Lithium hydroxide, at the same ionic concentration as sodium hydroxide, should require a lower calcium hydroxide availability to inhibit deleterious reaction because of the lower mobility of lithium ion, as has been previously discussed. Such a comparison is shown in Fig. 9, where it may be observed that lithium hydroxide does require less calcium hydroxide than does sodium hydroxide to effect comparable decreased flow rates in the cells. For the same ratio of deleterious to innocuous reaction products, that is, the same osmotic flow rate through the membrane, less calcium hydroxide is required because of the lower availability of lithium hydroxide, even at the same ionic concentration as sodium hydroxide, due to the lower mobility of the lithium ion. It might initially be conceived that the differences observed between lithium and sodium hydroxides could result from differences in the solubility of calcium hydroxide in the two solutions, although the relative solubilities are not known at the present time. However, the lower reactivity of lithium hydroxide as compared to sodium hydroxide in the absence of calcium hydroxide would appear to provide a serious obstacle to such postulation. Another aspect to which this concept of competitive rates can be applied is the effect of the aggregate particle size itself.

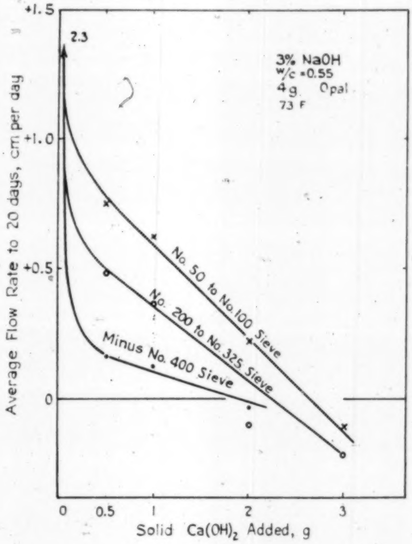

Fig. 10.—Effect of Calcium Hydroxide on Different Particle Size Ranges.

Influence of Particle Size of Aggregate:

Considerable research has been directed to the study of the effect of the particle size of reactive aggregate on the alkali-aggregate reaction. Finely divided siliceous additions to mortar or concrete have, in general, been effective in preventing abnormal expansion due to the reaction, although the exact mechanism by which this desirable result is obtained might appear somewhat vague. The deleterious reaction of relatively large particles of certain aggregates, even with low alkali concentration, has been reported (**14, 15**).

Reactive silica (opal) of various particle size ranges was studied by means of the osmotic cells, with particular reference to the effect of calcium hydroxide on the reaction products formed. The results of such experiments are shown in Fig. 10 and are of particular interest in that they directly show that the calcium hydroxide requirements for prevention of deleterious reaction products decrease significantly as the particle size of the aggregate is reduced. In these tests, particular care was taken in the preparation of the aggregate samples, in regard to both crushing and screening, to assure that the samples of the different particle size ranges were similar. It may be seen that at the same calcium hydroxide content considerably more osmotic flow was observed for the No. 50 to No. 100-sieve material than for the minus No. 400-sieve material. For the same degree of deleterious reaction (the same flow rate), significantly less calcium hydroxide was required by the finer aggregate.

These observations are similar to results obtained with mortars or concretes. Under otherwise comparable conditions, for a specific quantity of reactive aggregate, the finer the aggregate the less the ultimate expansive tendency. It is believed that these results can also be directly interpreted in terms of the competitive reaction hypothesis. For example, calcium hydroxide appears inefficient in inhibiting the reaction, presumably because of its low mobility through aqueous solution or cement paste. In mortar or concrete, therefore, it may be assumed that only the calcium hydroxide in very close proximity to the surface of the aggregate will be effective for reaction in any reasonable length of time. Hence the calcium hydroxide availability per unit of surface area of the reactive aggregate may be considered essentially constant for a particular cement. However, it is apparent that for a particular specimen or osmotic cell, containing a certain amount of alkali in solution, the greater the surface area of the aggregate the lower the availability of alkali per unit of surface area of the reactive aggregate. Therefore, as the average size of the aggregate particles is reduced, the surface area becomes greater, and the alkali becomes less available in comparison to the calcium hydroxide per unit of reacting area, and a greater proportion of the innocuous calcium silicate type of product is formed. Interpreted in another way, the results indicate that as the surface area of the aggregate is reduced (large particles of reactive aggregate or less reactive aggregate) smaller quantities of alkali will produce comparable degrees of mortar bar expansions or osmotic cell flows.

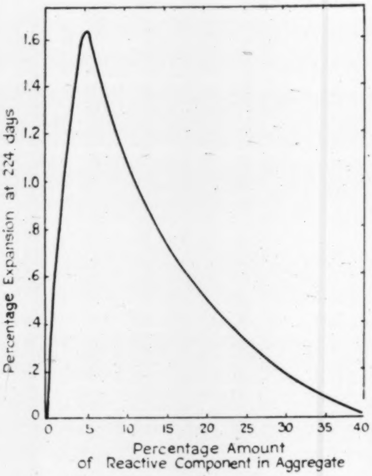

FIG. 11.—Effect of Amount of Reactive Aggregate on Expansion of Mortar Bars. From Vivian (**16**).

An interesting aspect of the alkali-aggregate reaction is the relationship between mortar bar expansions and the amount of reactive aggregate contained in various specimens. Such a relationship, as found by Vivian (**16**), is shown in Fig. 11. This figure indicates the sensitivity of mortar bar expansion to the amount of reactive aggregate used in the test. The observed effect can be simply interpreted on the basis previously presented and may be considered to be a composite of two simultaneous effects. The rising portion of the curve at the low percentages of reactive component represents the increased formation of deleterious alkali silicate product. Obviously where no reactive aggregate is present, no expansion can occur. As the reactive component is increased, more of the alkali available in the specimen is reacted, and hence greater expansions result until a maximum expansion would theoretically be obtained at some reactive aggregate content stoichiometrically related to the amount of alkali present. The descending portion of the curve, at the higher reactive aggregate contents, can be taken to represent, as was previously discussed, the effect of increased aggregate surface area. As the amount of reactive aggregate increases, the alkali available per unit area will be reduced, while the calcium hydroxide available per area of surface will remain essentially constant, since it is only that particular calcium hydroxide immediately adjacent to the surface that is available for reaction. The ratio of available alkali to available calcium hydroxide is therefore reduced, and lesser proportions of the deleterious alkali silicate are produced as the gross quantity of reactive aggregate is increased.

Data have been obtained by Hanna (14) and Woolf (15) indicating that under specific laboratory conditions abnormal expansion can be made to occur even with low alkali contents. This took place where only a relatively coarse fraction of reactive aggregate was used. On the basis of the osmotic cell tests, these observations appear interpretable, for it is precisely under these conditions of test that deleterious reaction could occur with low alkali concentrations. However, it has been pointed out by Lerch (17) that excessive expansions with low-alkali cements have not been reported in tests using naturally occurring aggregates. Presumably, the aggregate condition tested by Woolf could rarely, if ever, occur in practice. Discrete opal particles of about No. 16 to No. 30-sieve size are said rarely to be found in naturally occurring aggregates, and their presence without the simultaneous presence of finer opal particles would be very unusual. On the basis of the results obtained with the osmotic cells, it would appear that even No. 16 to No. 30-sieve opal would not produce deleterious reaction provided that finer opal was also present; this is in keeping with the significantly greater alkali tolerance normally observed in actual field practice.

Effect of Temperature:

The effect of temperature upon the reaction characteristics in the osmotic cells appears to be essentially normal in that higher temperature, at least in the range from 50 to 100 F, accelerates the reaction and the observed osmotic flow. Typical results are shown in Fig. 12. It may be noted that little if any reaction and flow occurred in approximately 12 days at 50 F, whereas a very great reaction and flow had occurred in only 1 to 2 days at 100 F. This influence of temperature corresponds with observations of expansion in mortars and concretes and should, of course, be considered in the study of the alkali-aggregate reaction.

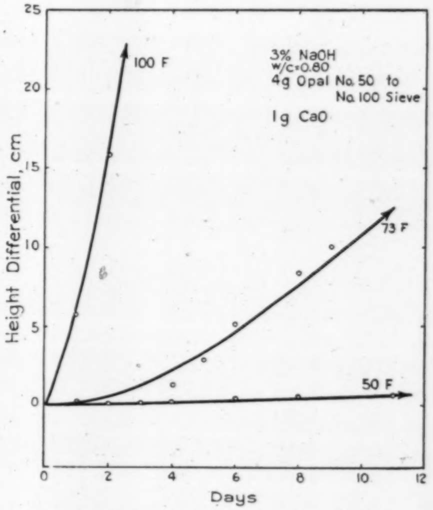

FIG. 12.—Effect of Temperature on Observed Height Differentials.

It is at present difficult, however, to anticipate the effect of temperatures above the normal range studied in the course of the reaction because of the combined influence of factors such as mobility effects, normal chemical acceleration due to temperature, decreased calcium hydroxide solubility, and decreased viscosity of the sodium silicate product.

DISCUSSION

The experimental results obtained in this study with osmotic pressure cells and in other studies of mortars and concretes can be interpreted in terms of a hypothesis based primarily on the concept of competitive reactions. The two competitive reactions involved are: (1) the formation of a deleterious swelling or osmotic product of the alkali silicate type, or (2) the formation of an innocuous, nonswelling, calcium silicate or calcium alkali silicate type of product. These two types of reaction products represent the extremes of the potential range in products obtainable in mortar or concrete; in general, the actual reaction products will possess characteristics between these extremes. Whether the over-all reaction favors the sodium silicate or the calcium silicate type of product will depend upon several factors. The course of the reaction seems to be interpretable in terms of the relative availabilities of alkali and calcium hydroxide at the reacting surface of the silica. If the alkali is much more readily available than the calcium hydroxide at the silica surface, the reaction products will favor the alkali silicate type. If the calcium hydroxide has greater relative availability than the alkali, the innocuous calcium silicate type of product will be formed. At present, neither the availability of the alkali or calcium hydroxide can be expressed quantitatively nor can the relative availability requirements for the different types of reaction products be delineated.

The specific quantitative determination of these availabilities appears to be an exceedingly complex problem that requires much additional study. It would appear that the availabilities of alkali and calcium hydroxide technically involve at least the following factors: the concentration or solubility, the mobility through aqueous solution or the permeability of the paste to the solution, and possibly certain electrokinetic phenomena. The data indicate that the mobility or availability of alkali is considerably less than might be expected. Supplementary tests have indicated that in the absence of other normally simultaneous effects, such as moisture deficiencies within the specimen, the rate of true diffusion of alkali through a neat cement paste membrane is relatively low.

Other observations imply that the mobility of calcium hydroxide through aqueous solution or, in particular, neat cement paste is exceedingly low, considerably lower than even that for the alkalies. It has been suggested by Steinour (18) that calcium ion is unable to move up to the reaction site at a rate sufficient to produce chemical equilibrium, and he has postulated that some special hindrance to calcium ion might exist. It would appear, however, that the calcium hydroxide is of such a low mobility that only the calcium hydroxide in the immediate vicinity of the silica surface, possibly only the amount within a fraction of a millimeter of the surface, can be considered as available to the surface within any reasonable length of time.

It has been shown how the data can be interpreted qualitatively in terms of the alkali present per unit area of reactive surface and the calcium hydroxide available per unit area of reactive surface and that the latter, within some reasonable limits, can be considered as essentially a constant factor. This concept explains the formation of alkali silicates in an environment that might be considered to have more than sufficient calcium hydroxide to form the calcium silicates. However, it is not certain to what degree the chemical composition of the cement paste influences the actual availability of calcium hydroxide. The osmotic cell provides a method of determining the availability of calcium hydroxide from pastes prepared with cements of different compositions. Substitution of crushed hydrated cement pastes for the calcium hydroxide normally added would directly reveal the influence of cement composition without a complicating simultaneous variation in alkali concentration, degree of hydration, water-cement ratio, and paste permeability. Such tests are currently under way.

It may be noted that in the development of this hypothesis of the alkali-aggregate reaction the necessity of a special retardant membrane surrounding the aggregate, previously suggested by other investigators (**9**), is avoided. It was proposed that a reaction product, permeable to water and alkali but retardant to calcium hydroxide and silicate, is formed during initial reaction at the aggregate surface, and that this reaction film is an essential requirement for any continued deleterious reaction. It is believed that, although some information indicates that such a membrane with these characteristics can be formed under certain experimental conditions, the postulation of such a reaction membrane in mortar or concrete is unnecessary, because the cement paste immediately surrounding the reactive aggregate particles would in itself possess analogous properties. The information obtained regarding the characteristics of this membrane indicates that under some conditions the calcium hydroxide can diffuse through a 0.025-in. thickness of the membrane at a rate sufficient to produce an innocuous product (**9**, **19**). However, under other conditions expansion is observed with No. 200 to No. 300-sieve opal, indicating that under these circumstances the calcium hydroxide could not diffuse at a sufficient rate through the membrane to prevent the formation of a deleterious product even though the membrane could not have been thicker than perhaps 0.001 in.

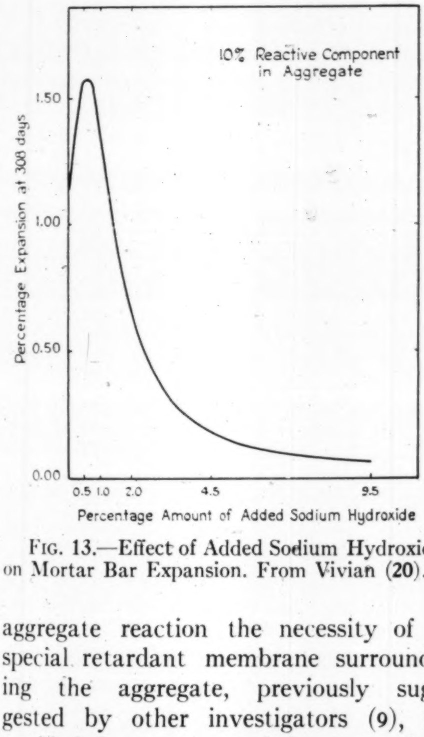

Fig. 13.—Effect of Added Sodium Hydroxide on Mortar Bar Expansion. From Vivian (**20**).

It has been observed by Vivian (**20**) that the expansion of mortar bars is not a simple function of the amount of alkali present. Just as in the case of his observed relationship between expansion and amount of reactive aggregate, it would appear that the expansion of mortar should increase progressively as the amount of alkali in the bar was increased until some alkali concentration was reached, stoichiometrically related to the amount of reactive aggregate. Beyond that concentration, the expansion might be expected to remain uniformly high, but actually a sharp decrease in expansion was observed. Results obtained by Vivian (**20**) are shown in Fig. 13. It is suggested that the rising portion of his observed relationship is due to the increased formation of alkali silicate as more alkali is added, but that the decreasing portion of the curve at the higher alkali concentrations may be due to one or more related phenomena. It is possible that, as the quantity of alkali is increased beyond some stoichiometric quantity represented approximately by the observed maximum expansion, the alkali content of the reaction product may become increasingly greater with a corresponding increase in the fluidity of the product. That large variations can occur in the viscosity of sodium silicates depending upon the alkali-silica ratio is revealed in data presented by Vail (21). His data indicate that the effect is substantial and that, for example, the viscosities of 33.6 per cent solutions of 0.256 $Na_2O \cdot SiO_2$ and 0.298 $Na_2O \cdot SiO_2$ are approximately 7000 and 50 centipoises, respectively. As the product becomes less solid or gel-like, it becomes more capable, under the impetus of internal swelling or osmotic pressures, of movement into the cement paste and source of calcium hydroxide immediately surrounding the reaction site, and the potentially deleterious product is rendered innocuous by reaction with calcium hydroxide. This mechanism could continue until all of the silica or alkali is substantially reacted.

However, there is an additional mechanism of considerable interest in this regard. It has been observed in supplementary tests that the permeability of neat cement paste to liquid movement decreases, perhaps significantly, as the solute content of the water is increased. Solutions of high alkali concentration apparently possess less mobility through cement paste than do solutions of lower concentration. Hence, as the alkali concentration is increased, the movement of water to the reaction site may be decreased; hence the rate of swelling is decreased. This would, of course, result in the observed decreased expansion with high alkali contents when the expansions are compared on a time basis. Also, as the alkali concentration is increased, the effective mobility of alkali through the membrane may be decreased, and if the effect is sufficiently pronounced, this could result in an actual decrease in alkali availability at the reaction site. This potential decrease in alkali mobility with increasing alkali concentration might then produce a twofold effect: not only would the concentration of alkali be decreased at the surface of the aggregate but also the concentration of calcium hydroxide should correspondingly increase (13), both changes being decidedly beneficial. These concepts will be the subject of further study but are offered at the present time as possible explanations consistent with present knowledge of the relationship observed by Vivian.

In the course of this study, certain special aspects were considered and will be briefly mentioned. A study is currently under way regarding the permeability of neat cement paste to aqueous solutions containing various solutes, such as alkalies, inorganic salts, and certain organic compounds. Preliminary results indicate that this investigation may provide information of importance to the study of the alkali-aggregate reaction, salt scaling of concrete surfaces, and other researches. Other related studies of ion mobilities and electrokinetics are under consideration, particularly with reference to, the potential role of inhibitors of the alkali-aggregate reaction.

Studies of the potential physical expansion *per se* of aggregates such as opal when wetted with alkali have indicated to date no expansive tendency, but the studies will be continued because of their importance to the alkali-aggregate reaction.

Consideration is being given to evaluation of the osmotic cell procedure as a rapid and acceptable method for determination of the reactivity of aggregates.

SUMMARY

An osmotic cell technique for the study of the chemistry and physics of the alkali-aggregate reaction has been described. The experimental data include the effect upon osmotic pressure of (1) the permeability of the neat cement paste membrane, (2) alkali concentration, (3) different alkalies, (4) calcium hydroxide, (5) particle size of aggregate, and (6) reaction temperature. Application of these results has led to the development of a hypothesis concerning the reaction of alkalies in concrete or mortar with reactive siliceous aggregates.

The hypothesis considers the reaction products of alkali and silica in concrete to range from a high calcium-alkali-silica gel of a nonexpansive type to an almost pure alkali-silica gel with an intense potential for producing expansion. The nature of the reaction product formed is dependent upon the relative availability of the alkali and calcium hydroxide to the area of the reactive surface and may change during the course of the reaction. If the alkali reaches the reaction site at a considerably greater rate than the calcium hydroxide, an expansion-producing gel is formed. If the calcium hydroxide reaches the reactive surface in sufficient quantities relative to the alkali rate, a nonexpansion-producing product is formed. Decreasing the alkali content or increasing the fineness or quantity of reactive aggregate will reduce the alkali availability per unit area of reactive surface, whereas the calcium hydroxide availability per unit area of reactive surface will remain relatively constant.

The influence of various factors upon the relative availabilities of alkali and calcium hydroxide, such as the inherent properties of cement paste, alkali concentration and particle size, and quantity of aggregate, have been discussed. The formation of expansive low-calcium reaction products in concrete which contains large quantities of calcium hydroxide is attributed to the low mobility and solubility properties of calcium hydroxide in the cement paste membrane surrounding the reactive aggregate. The mobilities of the alkali and calcium hydroxide are presumably not independent; each is affected by the permeability (capillary pore size, etc.) of the paste, the size of the hydrated ion complex, and possibly electrokinetic phenomena, or the surface charges of both the paste membrane and the reactive aggregate, or both.

It is further postulated that the nature of the reaction product does not alone control the expansion or lack of expansion in a concrete matrix, but that the permeability of the paste and quantity of water present determine the extent of osmotic pressure developed by an expansion-producing end product. If the permeability of the paste is high and considerable water is present, an expansion-producing gel may not produce over-all expansion of the matrix.

This hypothesis suggests the possibility that a fundamental and practical remedy to deleterious alkali-aggregate reaction might be obtained by physicochemical adjustment of the mobility functions of alkali and lime by additives (inhibitors) or surface treatment of aggregate.

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DISCUSSION

Mr. Bryant Mather.[1]—I would like to ask a question for clarification regarding the experimental procedure. The cell with which the results were obtained has two chambers separated by a neat-cement membrane. Since the conclusions relate to cement-aggregate reaction, does the fact that the membrane was composed of neat cement have any significance other than to provide a porous semi-permeable membrane of the characteristics which were provided by the several kinds of neat cement used? Is it correct that the cement in this experiment had nothing chemically to do with cement-aggregate reaction?

Mr. George Verbeck (*author*).—We believe that the use of a semipermeable membrane made of other than neat portland-cement paste would give very similar results, provided that the physical characteristics of such a membrane were the same as those of the membranes used. The amount of lime made available to the reaction by the neat cement paste membrane would be small, considering the exposed area and diffusion distance required, compared to lime mixed with the reactive aggregate. Other experiments were conducted using cellophane and porous alundum as semipermeable membranes with results similar to those reported for neat cement paste membranes. The paste membranes were selected primarily on the basis of stability, reproducibility, and convenience.

In addition, the neat cement paste membranes permitted study of the influence of water-cement ratio on the semipermeable nature of the membrane. For well-cured pastes we have found that if the water-cement ratio is relatively high, perhaps above 0.65 by weight, the membrane becomes partially permeable to the silicate ions. Silicate diffusion will affect the course of the reaction in concrete.

Mr. Mather.—The point is that the cement in the membrane participated in the experiment solely as a membrane with particular sorts of holes in it and was not a chemical participant in the reaction?

Mr. Verbeck.—The cement membrane was not a chemical participant in the reaction, but in some experiments the physicochemical properties of the paste were under study.

Mr. G. G. Christiansen (*written*).[2]—This is an interesting and thought provoking paper on a subject that is of great importance to all who are interested in durable concrete. However, there does seem to be a certain amount of ambiguity in the viewpoints expressed by the authors, such that the word "hypothesis" should not be forgotten. In addition, there is one instance where more laboratory data would have enhanced the value of this paper a great deal.

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[2] California Portland Cement Co., Colton, Calif.

Most of the ambiguity occurs in the one full paragraph on page 1120. There I find statements and counter-statements to the extent that most of what is said is cancelled out. However, an implication is left that some fixed percentage of alkali in the cement portion, called "threshold concentration," may be used as a dividing line between good and bad concrete when considering potential cement-aggregate reactions. I, for one, cannot accept that as true, on the basis of logic or a review of the literature, and I find it difficult to believe that the authors do either.

This latter belief is based on phrases by the authors themselves, such as "Obviously this threshold concentration for *each particular case* will be a function of several factors" (from page 1120), and other comments noted on pages 1122 and 1127. These comments, when added up, seem to be in agreement with the idea that good or bad cement-aggregate reactions are based on the relative proportions of alkali, calcium oxide, surface area of reactive aggregate, degree of reactivity of the reactive aggregate and moisture content. Porosity of concrete and temperature would also affect the whole system.

This thinking is very much in line with that expressed by D. O. Woolf, W. C. Hanna and by Vivian of Australia. Mr. Woolf suggested the importance of an "alkali-opal ratio" or "alkali aggregate ratio" and his data showed that harmful reactions could occur with as little as 0.22 per cent alkali. Mr. Hanna's observations were similar. However, the authors have seen fit to repeat on page 1124 a belief expressed by Mr. William Lerch which implies that the data and findings of Woolf and Hanna are of doubtful value because they were obtained under specific laboratory conditions that "could rarely, if ever, occur in practice." This reasoning is difficult to understand in a world that contains so many combinations that they practically exceed man's ability to comprehend them.

One last comment is again in regard to the full paragraph on page 1120. Here the authors claim to have "directly verified" the concept of "threshold concentration" (qualified by the phrase "in principle") and refer to Fig. 8 for their proof. This figure is undoubtedly based on good data and cannot be argued, but it is based on only one set of *specific laboratory conditions* and therefore hardly seems to be sufficient to justify any broad claim. Additional data obtained with the same test equipment, but with different conditions would certainly seem to be desirable and it would have increased the value of this paper.

MR. VERBECK.—The authors appreciate Mr. Christiansen's interest in the paper and the opportunity for amplifying certain comments which to him seem somewhat ambiguous.

It appears that two aspects are involved; the fundamental concept of threshold alkali concentration and the practical question as to what alkali concentration represents a dividing line between good and bad concrete.

If all factors of importance to the reaction are held constant except that the alkali concentration is increased, a concentration is apparently reached at which deleterious reaction will occur, this concentration being considered the threshold concentration for the given set of factors involved. The concept of threshold concentration is supported both theoretically and experimentally by the present work, the work of Lerch, and also of Powers and Steinour. As Mr. Christiansen points out, the authors believe that the threshold alkali concentration may differ appreciably from case to case as a function of several important factors as enumerated in the paper. For example, the use of a reactive component of low surface area could decrease the threshold alkali concentration whereas a finely divided reactive material might increase the alkali concentration required for deleterious reaction.

The authors therefore find no difficulty in agreeing with Mr. Christiansen that under particular circumstances harmful reactions can occur with as little as 0.22 per cent alkali.

Although the present report concerned laboratory tests in which certain variables could be separately and conveniently studied, the authors recognize that the practical aspects of the alkali aggregate reaction should include consideration of actual performance of field concrete, which would thus embrace a wide variety of aggregate combinations, cements, construction practices and exposure conditions.

Various investigations have been made of the actual performance of field concrete in relation to the alkali content of the cements used. All reports of such investigations reaching the authors have shown that concretes made with reactive aggregates and low-alkali cement have shown good performance in the field. Considering the wide variety and number of concretes involved, the use of low-alkali cement in actual field concrete appears to provide practical protection against deleterious reaction with a very high degree of assurance.

BASIC CONSIDERATIONS PERTAINING TO FREEZING-AND-THAWING TESTS

By T. C. Powers[1]

Synopsis

Questions about current test methods are raised and an alternative test suggested. Preparatory to this, knowledge about the mechanisms of frost action in hardened paste and in rock is summarized. Emphasis is placed on concepts of critical thickness and critical saturation, and the roles of air bubbles in paste and macropores in absorptive rock. Rapid freezing in the laboratory may destroy concrete that is immune to frost under natural conditions. In the laboratory, too, important effects of seasonal drying are not taken into account. A new procedure is proposed that takes category of field exposure into account and uses the period of immunity to frost attack as the primary measure of frost resistance.

Freezing-and-thawing tests for concrete were developed mostly within the past 25 years. They evolved during a period when our knowledge of the mechanics of frost action and of physical properties of concrete's components were meager and more erroneous than they are now, and thus while there was relatively wide latitude for differences of opinion. ASTM committees and other groups have attempted to standardize a test, without the hoped-for degree of success, and new attempts are under way. At present, the ASTM has four tentative procedures. They permit a wide choice of test conditions, especially with respect to rate of cooling, as is shown in Table I. In one method there is no restriction on the maximum rate of cooling (Method C 291); in another (Method C 290), it is limited only by the restriction that the difference between center and surface temperature of a specimen must not exceed 50 F, but the dimensions of the specimen are not specified and thus the restriction still permits a wide range of maximum cooling rates.

All four methods suggest starting the test on moist-cured specimens 14 days old, without preliminary drying, and keeping the specimens wet throughout the test. The test is to be continued for 300 cycles or until the "sonic modulus" has dropped to 60 per cent of the initial value;[2] the object is to measure the rate of deterioration and express it in terms of "durability factor."

Published reports indicate that test conditions actually differ more among various laboratories than is permissible under or suggested by the tentative standards. Cooling rates differ, particularly in the important range below 32 F,

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[2] The end point for C 292 is different—100 cycles in brine or 200 in water or until 60 per cent of initial E (Young's modulus of elasticity) is reached.

and various curing schedules are used. The amount of study being given these matters by ASTM and other committees shows that many are uncertain as to what the method should be. Some seem to feel that one set of conditions may be as good as another, the important thing being to treat all specimens alike. Those inclined this way are apt to prefer a fast-freeze method that "gets results" quickly. Some changed to fast freezing after air-entrained concrete was introduced on the ground that slow-freezing methods could not produce results that would "bring out the differences."

TABLE I.—ASTM PROCEDURES.

ASTM Designation[a]	Temperature Range, deg Fahr	Average Cooling Rate, deg Fahr per hr	
		Minimum Average	Maximum Average
C 290	0 to 40	13.3	...[b]
C 291	0 to 40	13.3	...
C 292	0 to 73.4	3.1	4.1[b]
C 310	0 to 40	5.7	8.0

[a] All methods appear in the 1952 Book of ASTM Standards, Part 3, except Method C 310 which appears in the 1953 Supplement to Book of ASTM Standards, Part 3.

[b] Difference between center and surface temperatures not over 50 F.

Cooperative tests now under way, sponsored by the Highway Research Board, may show clearly which of the ASTM methods ought to be used, but there is a possibility that they will fail to do this. If the four methods are aimed at the right objective and if any of them contains the right procedure for attaining that objective, that method should be discovered by comparative tests. But it may turn out that frost resistance should not be measured in terms of rate of deterioration, in which case each of the methods will fail ultimately to satisfy.

The object of all these methods is to measure rate of deterioration in the laboratory and from that to predict at least the relative rate of deterioration in the field. A principal purpose underlying the present discussion is to question such an objective and to suggest an alternative. This will require first a review of the fundamentals of frost action as the author now understands them.

FROST ACTION

Physical effects of freezing water in concrete may range from practically no effect to serious damage. When damage occurs, the source of stress may be paste, or it may be aggregate particles. In any case, it is due to dilation[3] of the component directly affected by freezing. Freezing water in a rock particle may cause the particle to dilate or to break. Hardened paste also may be caused to dilate beyond its elastic limit, the effect being a permanent enlargement without apparent rupture or, when the effect is severe, disintegration.

The mechanism by which freezing causes dilation or disintegration of a rock particle is somewhat different from that which causes paste to dilate. Differences are due to differences in internal structure. Aggregate particles are normally composed of crystalline minerals, and the spaces among these crystals into which water can penetrate are relatively few and large. In hardened paste the spaces accessible to water are exceedingly small and numerous; porosity—that is, capacity for water—is relatively very high. Because of these fundamental differences, it is advisable to discuss aggregate and paste separately.

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[3] It is convenient to use *dilation* to indicate volume change produced by freezing water in concrete, *shrinking* and *swelling* to indicate volume change due to wetting or drying, and *expansion* and *contraction* to indicate that due to temperature change. Freezing not only may cause dilation but also drying because ice extracts water from gel. The reverse of dilation is *collapse*.

FROST ACTION IN PASTE

Structural Changes Due to Cement Hydration:

While cement is hydrating, cement grains in paste become replaced by other physically and chemically different materials. The principal one is a granular substance called cement gel. Being granular, it has a characteristic porosity, approximately 25 per cent. The granules, called gel particles, are exceedingly small, and interstitial spaces among them are correspondingly small. These spaces, called gel pores, are, in fact, so small that water cannot freeze in them at any temperature within the range of interest (**1**).[4]

The space occupied by cement gel is more than twice that of the cement consumed in producing it. Consequently, gel not only replaces original cement but also fills some of the originally water-filled space. The degree to which the originally water-filled space becomes filled with gel depends on how much of the cement has become hydrated and on the amount of water-filled space originally present. In other words, it depends on the water-cement ratio of the paste and on the extent of hydration of the cement.

Residues of originally water-filled space constitute an interconnected network of channels through the gel, or cavities interconnected only by gel pores, depending upon the degree to which gel fills available space. These spaces are called capillary pores or capillary cavities or, in general, capillaries. They are large enough that water can freeze in them. They are not all the same size, however; some are so small that ice can exist in them only at temperatures below the normal melting point of ice. The amount of water that freezes in any given hardened paste is greater the lower the temperature.

Role of Alkalies and Other Solutes:

Hardened pastes normally contain sodium hydroxide and potassium hydroxide in solution (**2**). Consequently, while hydration of cement proceeds, alkalies become more and more concentrated in the chemically free water. This fact, as well as dimensional factors already mentioned, influences the amount of ice that can exist in the paste at a given temperature. As freezing proceeds, pure ice separates from the solution. Hence, freezing increases alkali concentration and lowers the melting point of ice. Presumably, effects of solute concentration and dimensional factors on melting point are additive. Alkali concentration is influenced by leaching; much of the author's work at the Portland Cement Assn. has been with pastes from which all the alkalies were leached before the first freezing.

Effects of Freezing:

Critical Thickness.—Physical effects of freezing a body of water-saturated hardened cement paste depend first of all on dimensions of the body. If the body is extremely large—that is, if it has virtually no boundaries at all and no air voids—all water that freezes must remain in the body and the body must increase in volume enough to accommodate the water-volume increase produced by freezing. Hence, the volume increase would be about 9 per cent of the volume of water that freezes. With a finite body, however, some of the excessive water-volume produced by freezing may escape from the body during freezing, and thus over-all dilation of the body will be less than what it would have been had none of the excess been expelled.

If the body of paste is a thin slab or a small particle, parts nearest "escape boundaries" (the surfaces through which excess water can be expelled) will not be directly damaged by freezing because all excess water can escape from those regions. If the body is sufficiently thick, inner parts will become dilated during freezing, and this will affect outer parts too; hence, the over-all effect of freezing in any given paste depends on thickness of the body. If the body is thinner than some critical limit, it can be frozen without damage.

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[4] The boldface numbers in parentheses refer to the list of references appended to this paper, see p. 1154.

Critical Saturation.—If a body of paste is not saturated, the largest spaces tend to be empty while the smallest remain full. Some spaces will be partly full. If any given capillary space is 91.7 per cent full before it freezes, it should be exactly full after freezing (assuming 9 per cent volume expansion). Since it contains no excess water, it will not contribute to hydraulic pressure that may be generated by freezing in other fuller spaces.[5] If it contains more than 91.7 per cent of its capacity, it must, of course, contribute to pressure; the more nearly full it is, the more it contributes. Therefore, for a given capillary space in hardened paste, 91.7 per cent is a critical degree of saturation.

If the paste as a whole is not saturated, water will not be uniformly distributed among the capillary spaces. The smaller spaces will tend to be fuller than the larger ones. Hence, freezing in a partially saturated paste may involve displacing water from smaller to larger spaces. Freezing in paste thus may produce some stress even when the over-all saturation coefficient is below the theoretical limit. Such stress is not likely to be destructive; indications are that a small loss of evaporable water enables a paste to withstand severe freezing.

Mechanism of Dilation:

Hydraulic Pressure.—When conditions and body dimensions are such that freezing produces dilation, the dilation may be caused in one or all of three ways: hydraulic pressure; growth of ice bodies; osmotic pressure. If paste porosity is relatively high and freezing is rapid, dilation will be caused by hydraulic pressure. Hydraulic pressure is generated when growing ice crystals displace unfrozen water, causing water to flow through the unfrozen parts of the body. Pressure is due to resistance to such flow, a mechanism that has been discussed in a previous publication (3). Stress produced by this mechanism appears at the same instant that freezing begins.

Growth of Capillary Ice.—If the body contains relatively few capillaries, dilation is apparently not due primarily to hydraulic pressure; when ice begins to form at relatively few points, resulting hydraulic pressure is too low to cause significant dilation. However, once a body of ice has formed in a cavity, that ice acquires ability to draw water from the surrounding unfrozen regions as soon as temperature drops below the melting point of ice in the cavity.[6] While water is being drawn from regions surrounding a body of capillary ice, paste tends to shrink, but this tendency may be more than overcome by growth of ice crystals, the over-all result being dilation. Since crystal growth follows after temperature begins to fall, dilation may not be apparent the same instant that freezing occurs. Also, it does not stop as soon as cooling ceases. In a typical experiment on a relatively dense paste, temperature was held constant after it became low enough for freezing to start. The paste continued to dilate at a fairly steady rate for the next 7 hr and was still dilating when observations stopped (**4**).

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[5] The structure of paste is thought of as closely packed particles (the gel) with occasional gaps (capillaries) and nongel solids, principally crystalline calcium hydroxide. Pressure generated in a capillary would probably be distributed over most of the whole cross-section, through water in the unfrozen gel pores and smaller capillary cavities. Thus freezing in a given capillary contributes to a "general fund" of hydraulic pressure.

[6] It should be kept in mind that, in these exceedingly small spaces, melting point is lower the smaller the spaces.

Osmotic Pressure.—The foregoing remarks pertaining to diffusion of water from gel to an ice body and consequent dilation apply accurately only to capillary water containing no alkali or other highly soluble substances. Although most of our experiments have been done on alkali-free pastes, effects of alkalies have been seen and are believed to be understood. If temperature is such that a given capillary filled with pure water would just freeze solid, the same cavity filled with an alkali solution would become only partly frozen at the same temperature. The end result would be a solution having the right concentration to be in equilibrium with pure ice at the existing temperature. At this point it is important to recall that material bordering each capillary is cement gel containing gel pores and solution, and that ice cannot form in these pores because of their smallness. Therefore, if the solution in gel pores and that in capillary cavities are in thermodynamic equilibrium with each other before freezing, they cannot be at equilibrium after freezing because freezing concentrates the solution in the capillary cavities without producing an equal change in concentration in the gel pores. Thus, freezing should immediately produce a tendency for the solute in the capillary water to diffuse into the region of lesser concentration, the contiguous gel water. At the same time, gel water tends to diffuse into the concentrated solution in the capillary. While the concentration differential exists, a dilation tendency exists which, when opposed, will appear as osmotic pressure. The magnitude of osmotic pressure will depend on concentration difference

Osmotic pressure has been observed in experiments on permeability of hardened paste (**5**), and other experiments have demonstrated that paste has the necessary semipermeability (**6, 7**). In the permeability tests, conditions were such that leaching of alkali from a neat-cement plug produced different concentrations on upstream and downstream sides. Differences were enough to cause reversal of flow against a 3-atmos head in some cases. There is thus no reason to doubt that local inequalities of concentration *within* such a specimen would also produce osmotic pressure.

The kind of pressure produced by osmosis should not be much different from that due to growth of ice crystals. Pressure from growing ice is not due directly to the solid itself but to the drawing of water molecules into the adsorbed film that separates ice from the cavity wall. This gives rise to a swelling pressure closely akin to osmotic pressure.

Thus, whether or not capillary water contains dissolved alkalies, freezing in a relatively dense paste can produce dilation. It may be produced by water driven to ice bodies by a potential produced by falling temperature, or by water driven to a solution—osmosis—or it may be due to both causes. Experimental work has not yet revealed the relative importance of osmotic pressure. It need not be a major mechanism in ordinary freezing-and-thawing tests, for all the effects of freezing have been observed when freezable water contains only a trace of alkali. However, osmotic pressure may be a major factor in "salt scaling." When the normal solute content is augmented in regions near the surface of pavement by salts applied for ice removal, osmotic pressure in partially frozen capillaries may be the dominant source of stress. This is an inference not yet checked experimentally.

Factors Determining Critical Thickness:

As stated previously, whether or not a body of paste is damaged by freezing when it is water-soaked depends on its thickness, or on its diameter if it is a particle. Where damage is caused by hydraulic pressure, critical size or thickness depends on factors determining intensity of hydraulic pressure. The principal factors are: coefficient of permeability, coefficient of saturation, strength, and rate of ice production, which depends on rate of cooling and sometimes on extent of supercooling.

When stress is produced by growth of capillary ice, stress intensity *in a given paste* should be controlled by the length of time during which temperatures are low enough to support growth of ice crystals, and the thickness of the body. Growth of ice bodies in the specimen may be limited by the effect of ice formed on escape boundaries. These surface bodies of ice as well as internal bodies (capillary ice) are able to draw water from the gel and to grow as temperature falls below their melting point. Surface ice competes with capillary ice for unfrozen water in the paste. Given time, it eventually wins the competition, for shrinkage puts capillary ice under pressure while surface ice remains free. The result is over-all shrinkage rather than dilation. The thickness of paste layer fixes the length of time during which capillary ice remote from escape boundaries can produce dilation. When the thickness is below a critical limit, dilation does not occur (**4**).

The competition that controls growth of capillary ice should also limit osmotic pressure. The concentrated solution in a given capillary space will not be able to obtain water from the less concentrated solution in the surrounding gel unless the saturation of the gel is above a certain degree; the solute in the partly frozen capillary must have reduced the vapor pressure of capillary water below that of the gel water. The vapor pressure of gel water depends on the combined action of surface forces and solute and is lower the lower the degree of saturation. Therefore, ice on the surface of an escape boundary at a temperature below its melting point may be able to lower the water content of the gel to a safe level before destructive osmotic pressure can develop inside the body. Ice on an escape boundary also formed out of a solution, and therefore it produces a concentrated solution that may cover part of the escape boundary, which is likely to be a void boundary. This concentrated solution should compete with the solution in the capillary cavity and thus should tend to prevent dilation.

Augmented Escape Boundaries—Entrained Air:

Hardened cement paste in concrete normally has insufficient escape boundaries. Slabs, beams, columns, or other structural members are much too thick for visible surfaces to serve as escape boundaries needed by excess capillary water in paste. For the most part, paste is in contact with rock particles, and the interface between rock and paste is not an adequate escape boundary even though rock particles may be able to absorb some water. Air voids normally entrapped in concrete during placing, the so-called natural voids or entrapped-air voids, provide effective escape boundaries but not enough ordinarily to prevent the paste from dilating when it freezes, at least in laboratory tests. The voids are too few and far between.

Introduction of additional air voids by using an air-entraining agent is the means of providing escape boundaries sufficiently close together. Indications are that the computed space factor, based on air content and specific surface of air voids, should be less than about 0.01 in. (**8**).

The extreme smallness of the maximum permissible spacing factor is required by the particular combination of physical characteristics found in hardened cement paste. Relative to most rocks, hardened paste has high porosity (high capacity for freezable water) and low coefficient of permeability. In addition, it has ability to hold a considerable amount of unfrozen free water at temperatures far below normal freezing point. It is this characteristic that gives rise to growth of capillary ice or osmotic pressure after the initial freeze.

Frost Action in Rock

Studies of frost action in hardened cement paste contributed also to our understanding of frost action in rock in general, and concrete aggregates in particular. They lead to a picture that, for the most part, is harmonious with that drawn from studies by earlier investigators, particularly Thomas (1938) (9). The significance of early rock studies with respect to concrete aggregates was succinctly stated by Rhoades and Mielenz in 1946 (10): "The effect of an aggregate particle upon freezing-and-thawing durability of concrete depends largely upon the ability of the particle to attain a high degree of saturation while it is enclosed by cement (paste)." Yet the concept of critical size does not appear clearly in these earlier studies,[7] and the real difference between physical characteristics of paste and those of rock was not known. Probably most persons who speculated about it assumed that pores in hardened portland-cement paste were larger than those in "sound" rock, whereas, as is now known, the opposite is usually true. It seems worthwhile to restate ideas developed in earlier studies in such a way that the concept of critical size may be added and the significance of the real differences between paste and rock brought out.

Mechanism of Dilation:

Among rocks commonly found in concrete aggregates, pores accessible to water are much larger than those in hardened cement paste, as already pointed out. One consequence of this is that once freezing starts in saturated rock nearly all the water freezes near the normal melting point. In most rocks (though not all), there is no significant amount of water that can cause crystal growth after the initial freeze. If growth occurs, as it sometimes does (11), water may be obtained from an outside source. Therefore, it seems fairly certain that forces produced by freezing in rock are predominantly hydraulic. The mechanism of frost action in rock is generally simpler than it is in hardened paste.

Dilation of rock due to crystal growth, and without an outside water source, is not unknown, however; some features of Thomas' experiments (9) cannot be explained if this phenomenon is overlooked. He found, for example, that a certain red sandstone slowly dilated while its temperature was lowered 10 C in a period of 57 hr. He found, also, that with certain rocks in which as much as 20 per cent of the free water remained unfrozen, holding the temperature constant at, for example, −5 C, caused gradual shrinkage, the shrinkage being observed over periods as long as five days. Such behavior could be accounted for either by growth of ice on the surface of the specimen, the ice drawing water from the interior, or a similar crystal growth in partly filled macroscopic voids if any were present. Such phenomena probably play no significant role in ordinary freezing-and-thawing tests in which low temperatures are maintained for a short time only; in such tests, behavior of rocks should usually be determined by effects of hydraulic pressure generated by the initial freeze. However, effects of crystal growth may be significant under certain field conditions. During long cold spells, ice bodies in pores of rock particles in concrete could grow by drawing unfrozen water from the surrounding cement paste. If the paste can obtain water from an outside source, dilation might eventually be produced, though the required combination of circumstances is probably rare.

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[7] Thomas, for one, seems to have had size in mind when, for example, he says that the amount of ice (water) extruded from a stone during freezing "will be dependent upon size and shape of specimen." But he did not emphasize the point in the way that the author aims to do here.

Generation of hydraulic pressure has been assumed by various previous investigators. For example, Jones, reporting studies of brick in 1907 (12), produced what is still a fairly up-to-date statement of the factors controlling intensity of hydraulic pressure during freezing.

Critical Size of Rock Specimens:

Specimens of rock as well as paste bodies may have a critical size. Experiments show that critical size for rock is much larger than that for hardened paste; whereas the critical size of a paste particle would be expressed in mils, that of a rock particle would more than likely be measured by the inch or in tenths of an inch.

Difference in critical size is due to difference in factors controlling hydraulic pressure. Among these is the rate of freezing; for a given kind of rock frozen in air or water, stress produced by freezing should be greater the higher the rate of ice production. When Thomas froze rock prisms 1½ in. thick, the effect was as would be expected: the faster the rate of freezing the greater the dilation. In another experiment, he found increased damage when the specimens were frozen with carbon-dioxide snow as compared with freezing more slowly. In other experiments, he used prisms of different size from the same rock and found that, when rate of freezing was constant and sufficiently high, damage was greater the larger the specimen. From the point of view adopted for this discussion, it seems that critical size is determined principally by porosity, coefficient of permeability, degree of saturation, strength, and rate of freezing. As will be seen, it depends also on homogeneity.

Most rocks have capacities for freezable water smaller than those of pastes. Some have so little capacity that they cannot be overstressed by freezing even though none of the excess water is expelled during freezing, in which case there is no critical size.

Some rocks seem to have "built-in" escape boundaries, that is, naturally occurring macroscopic voids that seldom, if ever, become water-filled. Willman (13) found good correlation between frost resistance and macroscopic porosity among various Chicago area dolomites. One-inch pieces having relatively high concentration of macroscopic pores withstood 790 cycles of freezing and thawing without significant damage. Rhoades and Mielenz (10) say "Many vesicular basalts, containing abundant large pores, have exhibited excellent durability in both field and laboratory concrete." If the number of macroscopic voids per unit volume of absorptive rock is right for the permeability, porosity, and strength of the rock substance around the macroscopic voids, the rock cannot be damaged by freezing and there should be no critical size. Such rock is protected by macroscopic voids in the same way that paste is protected by entrained air bubbles.

These considerations of critical size seem to apply to some of the data presented by Rice (16). He reported freezing-and-thawing tests of limestone cylinders representing rocks from various ledges and quarries. All test cylinders were the same size, $1\frac{3}{4}$ by 2 in. All were first dried, then some of each kind were immersed for 24 hr, and some were evacuated and immersed for the same period before the first freeze. In one group having "vacuum absorptions" ranging from 2.6 to 6 per cent, every vacuum-treated specimen permanently elongated as much as 0.1 per cent during 2 to 9 cycles. In a second group having vacuum absorption ranging from 2.7 to 8.4 per cent, none elongated more than 0.02 per cent in 50 cycles. A third group having *low* porosities all elongated rapidly.

All specimens of the first group were nearly saturated at the start, 94.7 to 100 per cent. They dilated rapidly, apparently because they could not expel excess water without generating destructive pressure; in other words, the test cylinders were larger than the critical size for these materials and the rate of freezing.

In the second group, two of the specimens had "vacuum absorptions" of 8.4 and 7.1 per cent and were 84.2 and 100 per cent saturated at the start. Yet they elongated only slightly, about 0.02 per cent. It seems safe to infer that in these cases the test cylinders were only slightly, if at all, larger than the critical size for these materials and test conditions. The rest of the specimens of the second group were below 91.7 per cent of saturation even after 50 cycles and, therefore, might have been able to undergo freezing without necessity for dilation or expulsion; their elongations ranged from 0.005 to 0.02 per cent. However, lack of complete saturation, even though the specimens were initially evacuated, suggests that some of these specimens contained macropores. In other words, their capillary systems might have been saturated or nearly so at the start, but they did not expand because macropores, in effect, reduced the size of the specimen.

The behavior of the third group, that comprising rocks of low porosity, suggests that these rocks were so fine textured and free from macropores that little or no water escaped during freezing and that a large part of the dilation produced by each freeze was permanent. Consider, for example, one sample that contained only 0.27 per cent water by weight or about 0.68 per cent by volume at the first freeze; it elongated 0.1 per cent in 10 cycles, which is a dilation of 0.3 per cent. To see how such a small amount of water could produce dilation, let us assume that during each thaw the sample absorbed an amount of water equal to the dilation produced by the previous freeze, and that each dilation was equal to 9 per cent of the water content. After n cycles, the volume change of the water, ΔV, expressed as per cent of specimen volume, would be:

$$\Delta V = 0.68\,[(1.09)^n - 1]$$

For $n = 10$ cycles, this becomes:

$$\Delta V = 0.9 \text{ per cent}$$

which would correspond to an elongation of 0.3 per cent.

This calculated result is three times the observed change. It shows that it is not necessary to assume a water content increase equal to the maximum possible dilation from the preceding freeze; some accommodation of displaced water, or some collapse during each thaw, could have been assumed to account for the observed results. It works out that the "interest rate" would be 3.7 per cent instead of the possible maximum, 9 per cent. The indication is that the sample was elongated by the first freeze, and by each succeeding one, beyond its limit of elastic extension. The sample seems to be composed of a material having relatively low "extensibility" and exceedingly fine texture.[8]

Critical Saturation Point of a Rock Particle:

If a piece of homogeneous rock is so big that practically no water can escape from it during freezing, the piece must dilate enough to accommodate the increase in water volume produced by freezing. If the water content is uniformly distributed and all of it freezable, dilation should be zero when the saturation coefficient is 0.917. It should be a maximum when the coefficient is 1.0. Critical size for a given rock should thus depend on saturation coefficient. When the coefficient is 0.917, critical size should be infinite; when it is 1.0, critical size should be minimum for the rock in question.

These statements should generally be true for homogeneous rocks in which water is uniformly distributed. However, attempts to verify the theoretical critical saturation point have generally not been successful. When saturation coefficient exceeds 0.917, probability of failure on freezing is high but not certain; it depends on specimen size in relation to critical size. Probability of safety when the coefficient is below 0.917 is *not* high; some samples of rock or of concrete aggregate with coefficients far below the theoretical limit have been damaged by freezing.

The concept of critical size helps to explain why, on the whole, experiments have not confirmed the theoretical saturation limit. If the rock is mineralogically homogeneous, and the piece is *larger* than the critical size for freezing at a given rate, it should be damaged by freezing if any part of it larger than the critical size is saturated. For example, if the piece is twice as large as the critical size and if 75 per cent of it is saturated and the rest half-saturated, the piece should be damaged by freezing, although the over-all saturation coefficient would be only 0.875.

Consider, also, a rock such as one of those reported by Willman (13), containing macropores in addition to capillaries. The capillary system could become saturated while the macropores remain practically empty. If the distances along rock capillaries from pore to pore exceed the critical thickness for that kind of rock and given freezing rate, freezing will produce damage. The over-all coefficient of saturation based on total porosity might or might not appear to be safe, depending on the volume of macropores in relation to the volume of capillaries in the rock.

Other examples may be found among mineralogically heterogeneous rocks. A coarse textured rock enclosing a fine textured lens or seam of shale or clay might be damaged when frozen at a relatively low over-all saturation coefficient. In this case, the fine textured part would probably be nearly saturated while the coarse textured part could be nearly dry. If the thickness of the fine textured part exceeded the critical thickness for the substance composing that part, freezing should produce damage. An extreme case of this kind is a specimen containing a weak, permeable bedding plane. In the neighborhood of this plane, critical thickness could be very small; freezing could cause splitting of an already thin slab. An over-all saturation coefficient might tell nothing of this condition.

Thus, it is seen that, although the concept of critical saturation is essential to understanding frost action, consideration of various pertinent facts leads away from the conclusion that any particular saturation coefficient can be used as a generally applicable criterion for safety or danger from frost action.

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[8] In answer to an inquiry after the above was written, Mr. Rice kindly sent the author a sample of each of the rocks discussed here. Just as the test data had suggested, the rocks of the first group were fine textured and free from macropores; those of the second group were coarse textured (possibly one exception) and some contained macropores; those of the third group seemed exceedingly fine textured and were completely free of macropores.

Porosity of Rock and Frost Resistance:

For the same reasons that a single limit for saturation coefficient is an unsatisfactory criterion for frost resistance, total porosity is also an unsatisfactory criterion. Poor correlation between frost resistance of rock and total porosity have been reported repeatedly (**15**). Good examples have already been cited in the data of Rice (**16**) and Willman (**13**). Attention should be focused on rock texture and occurrence of macropores rather than total porosity.

Critical Size and Critical Saturation of a Rock Particle in Concrete:

Twenty-five years ago Scholer (**14**) reported: "It seems that some material which is not broken down when frozen alone does break down when frozen embedded in concrete." Many corroborative experiences could be cited. Sealed by paste, each rock particle in concrete is practically a closed container; it must be able to accommodate its water content during a freeze, or become a source of stress. Regardless of rate of freezing or rock characteristics, some water must be expelled into the surrounding paste if the over-all saturation coefficient is much above 0.917—or dilation must occur. The paste itself is almost certain to be saturated if the aggregate embedded in it is nearly so; hence, it has no capacity for excess water. If air bubbles are present, they may receive some of the excess from the aggregate but at the price of generating high pressure, for the paste around the bubbles and coating the aggregate usually has a very low coefficient of permeability. The pressure generated around large particles would, of course, be greater than that around small particles, at equal degrees of saturation.

A rock particle in concrete may be a source of stress even when its saturation coefficient is below 0.917. If the particle is bigger than the critical size or if it is mineralogically heterogeneous, its critical saturation coefficient may be considerably below 0.917. Similarly, the critical saturation coefficient for the aggregate as a whole may be almost any value (**17**). If the aggregate comprises a significant number of readily saturable particles, these particles may produce dilation while the rest remain harmless. Various observations, particularly those of Wray and Lichtefeld (**18**) and of Lewis (**17**), suggest that a principal difference among different kinds of rock particles is the rate at which they become saturated when given free access to water.

Continuity of Pore System:

This section on Frost Action in Rock is based on the assumption that rocks contain an interconnected system of pores. The pores may comprise cavities as well as capillaries and, if so, the cavities may be interconnected by the capillaries. Capillaries are thought of as interstitial spaces among grains composing the rock. These spaces might be due to imperfectly joined crystals, or capillaries in the cementing material between grains, as in sandstone. If cavities are present, their walls are composed of absorptive rock; hence, cavities are interconnected by capillaries. The fact that a rock is able to absorb water is the basis for making this assumption as to structure.

Other authors have made different assumptions. Washburn (**19**), for example, described six kinds of pores as follows: (1) closed pore or bubble; (2) channel; (3) blind alley; (4) loop; (5) pocket; (6)

micropore. Micropores were defined as spaces having molecular dimensions, not penetrable by water. Channel pores correspond roughly to what are here called capillaries. Apparently, the closed pore, blind alley, and pocket were thought necessary to account for the fact that rocks are able to absorb by capillarity less than their total capacity for water. But such an assumption is really not necessary. The physics of capillary penetration will nicely account for the difficulty of filling cavities in a system of capillaries.

Obviously, no single assumption as to structure can apply to all rocks, but it is perhaps permissible to make one assumption about rocks able to absorb water. The assumption is, as already indicated, that their structure is granular and that absorption occurs through a continuous system of interstitial spaces. Since the walls of macroscopic voids are made up of this same granular structure, they too are interconnected.

Perhaps the best basis for justifying the assumption is the reasonableness of the consequences of doing so. Observed relation of specimen size to effect of freezing, for example, is satisfactorily explained by the hydraulic pressure theory and by assuming continuity of capillaries.

DISTRIBUTION OF MOISTURE BETWEEN PASTE AND AGGREGATE

The Saturated State:

Concrete contains a complex capillary system, and within the system are numerous cavities. The capillary system comprises the systems in individual absorptive pieces of rock, and gel pores and capillaries of hardened paste.[9] Cavities comprise various macropores: those in rock; entrained air bubbles; voids in the mortar due to imperfect consolidation of the mix; sometimes fissures under rocks formed during the bleeding period. From the practical viewpoint, a system of capillaries and cavities such as this presents two distinct stages of saturation. The first stage is that which can be attained by capillary absorption alone in a period much shorter than, say, a geological age; it constitutes complete filling of the capillary system or a close approach to it. Attaining the second stage requires filling the macropores. That can be accomplished in a short period only by first removing most of the air in the cavities and then augmenting capillary forces with externally applied pressure. Otherwise, the second stage of saturation can be produced only by immersing the specimen for no one knows how long a time. The required length of time no doubt differs with different rocks and with conditions conducive to displacing or dissolving entrapped air. The main concern here is with saturation of the capillary system. Macropores may be regarded simply as boundaries of a body having very complicated shape. In order to keep this concept in mind, the term "saturation of capillary system" will be used.

The Partially Saturated State:

Water in partially saturated concrete may be thought of as being in a state of tension, that is, it behaves as if under a negative hydrostatic pressure. One manifestation of this state is a reduced tendency to evaporate. Hence, at a given temperature, relative humidity inside unsaturated concrete is less than 100 per cent. If the state of tension of the water in concrete is not everywhere the same, internal humidity will be correspondingly unequal; hence, humidity can be used as an indicator of states of hydrostatic tension. The same ideas can be expressed in terms of water's free energy: differences in humidity from point to point indicate differences in free energy (20).

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[9] In other connections, a distinction was made between gel pores and capillaries in paste. But here they may be lumped together; they are fundamentally alike with respect to water absorption. By definition, paste contains no macropores; air bubbles are not part of paste.

The underlying principle governing moisture distribution in partially saturated concrete can be stated as follows: at constant temperature, moisture tends to move from regions of high humidity to regions of lower humidity, that is, it tends to move in such a way as to equalize hydrostatic tension or to equalize free energy. At constant temperature, relative humidity in rock or concrete is a function of degree of saturation. If temperature is not constant, if it varies from point to point in the system, degrees of saturation will tend toward different values from point to point depending on the relationship between entropy and water content, a complex matter that can be avoided here.

Degrees of capillary saturation of rock corresponding to a given humidity are usually much different from what they are in paste. Rock usually holds little or no water at, for example, 50 per cent humidity, but hardened pastes may contain different amounts ranging approximately from 40 to 90 per cent of saturation, depending mostly, but not exclusively, on porosity of the paste.[10] At 90 per cent relative humidity, hardened paste may be nearly saturated while rock may still be nearly dry.

At 100 per cent relative humidity, both paste and the capillary system of rock may be nearly saturated, but neither is likely to be completely saturated; after attaining equilibrium moisture content by exposure to saturated water vapor, either paste or aggregate may take up additional water when submerged. Paste, however, is likely to become the more nearly saturated when exposed to water vapor. It is because of these relationships between degree of saturation and relative humidity that hardened paste in concrete should generally be nearer saturation than the capillaries in rock, unless both are saturated.

The principles discussed above lead to the conclusion that liquid water cannot flow spontaneously from a fine textured material into a coarse textured one until the fine textured material has reached a sufficiently high state of saturation. Thus, when dried concrete is placed in contact with liquid water, hardened paste tends to become saturated before the rock capillaries do. This means that aggregate particles in dry concrete can ordinarily obtain very little water from the outside until the hardened paste is almost saturated. It means also that air bubbles and other macropores cannot become filled until the surrounding material is saturated, and, as emphasized before, even after that they are difficult to fill.

These considerations pertaining to water distribution explain why concrete may sometimes be damaged by frost even though the water content of the aggregate is at a safe level and the over-all saturation coefficient seems low. If a drying period reduced the water content of the whole concrete to a safe level, absorption of water during a freezing-and-thawing test will generally raise the saturation coefficient of the paste to a dangerous level before the aggregate can recover much of the water previously lost. If the paste is not protected with entrained air, freezing and thawing produces relatively rapid deterioration, which may be followed by aggregate failure as the paste loses its ability to seal the aggregate.

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[10] Another important factor is hysteresis in the water content *versus* humidity relationship. The amount of water held by paste at a given humidity depends in part on the past history of the sample and particularly on whether equilibrium water content is being approached from above or below.

Concrete in service may be exposed to air on one side and to water on the other—examples: a pavement slab in contact with moist subgrade; a wall retaining damp earth; a dam. One side remains wet or damp; the other is subject to seasonal variations. The pavement slab will tend toward a comparatively constant degree of saturation at the bottom, the degree depending on composition of subgrade and on drainage conditions. The upper part of the slab will undergo much wider fluctuations in moisture content for obvious reasons. The length of the wet season in relation to the dry season, together with absorption characteristics of concrete, of rock particles of the aggregate, or both, determine whether or not rock particles near the exposed surface ever reach dangerous degrees of saturation. The relatively constant level of saturation maintained near the bottom of the slab by subgrade conditions depends to a modified degree on the same factors.

A sound aggregate particle in concrete might, therefore, be defined as one that remains at a safe saturation level throughout the freezing-and-thawing season of every year. As Walker (21) and Sweet and Woods (22) have shown, a given kind of aggregate may remain sound in one situation but not in another; in Indiana, the performance of coarse aggregates correlated well with moisture conditions in the subgrade. Many have observed that certain chert particles reach a dangerous state of saturation during a wet season if they are situated near an exposed surface. Such particles so situated produce the well-known pop-outs. Examples can be found of air-entrained concrete pavement pitted with chert pop-outs, but otherwise undamaged; evidently, with certain kinds of chert and with safe subgrade conditions, the state of saturation more than an inch or so below top surface does not become dangerous.

FIVE IMAGINARY EXPERIMENTS

By way of summarizing the principles developed in preceding pages, let us perform five imaginary experiments. These "experiments" will deal only with the simplest aspects of freezing phenomena in concrete. Deviations in behavior that would be introduced by factors not considered should be fairly obvious.

1. Imagine a large body composed only of an aggregation of mineralogically homogeneous rock particles and interstitial air-filled spaces. The particle sizes range from the usual minimum sand size to a large coarse-aggregate size. Each particle is presumed to be saturated and to contain no empty macropores. Also, the capacity of each particle for freezable water is such that the particle cannot, with impunity, serve as a closed container; it is incapable of dilating elastically enough to accommodate the water volume increase produced by freezing. When this body freezes, excess water produced by freezing should be observed to ooze out of particles into air-filled interstitial spaces, freezing as it emerges, just as Thomas observed it in experiments of different but related kind (9). Among particles smaller than a certain size, expulsion of the excess will be complete; among larger particles, the rocks will have dilated sufficiently to accommodate some of the excess, or they will have become fractured. This imaginary experiment illustrates the concept of critical size in an aggregation of vari-sized saturated rock particles. If the experiment is repeated and different rates of freezing used, it is seen that the faster the freeze the smaller the particles subject to breakage.

2. For the second experiment, let us take an identical body of aggregate, fill the interstitial spaces with cement

paste,[11] and allow time for the paste to harden under curing conditions that prevent the paste from extracting water from rock particles. All the originally air-filled space in the body has now been replaced by hardened paste, and the aggregate remains saturated. The effect of freezing is immediate and catastrophic; neither water-soaked paste nor individual rock particles can safely get rid of excess water produced by freezing. This experiment shows the effect of making closed containers of aggregate particles and of using unprotected paste.

3. In the third imaginary experiment, let us start with the same aggregate, but this time fill the interstices with a mixture of paste and air bubbles. On freezing at moderate rate, the paste is able to get rid of its excess water; it does not dilate, but instead tends to contract. Saturated rock particles enclosed by paste still perform as virtually closed containers and are only a little better off than they were before. This experiment shows that protecting the paste fails to protect saturated aggregate particles.

4. For a fourth imaginary experiment, let us begin with the same aggregate, but this time let the rock particles be dry and the interstices filled with bubble-protected paste. Freezing at moderate rate causes no distress in rock particles because none is critically saturated. Freezing-and-thawing cycles are continued, allowing water absorption during thawing. Finally it is learned how long, or how many cycles, it takes for a significant number of particles to reach the dangerous level of saturation. This experiment demonstrates conditions producing limited immunity to frost and measures the length of time that immunity will last under certain laboratory conditions.

5. For a fifth experiment, a different aggregate is used, one comprising absorptive particles in which are numerous macrovoids, or one comprising nonabsorptive particles. The interstices are filled with bubble-protected paste, cured thoroughly. Measurements during freezing show shrinkage rather than dilation. This experiment demonstrates one set of conditions that gives practically permanent frost immunity.

FREEZING-AND-THAWING TESTS

Natural processes occur under so many different conditions that none is typical. In the field, the effect of any given freeze depends on the previous history of the concrete, particularly on the combination of circumstances that determine its water content and distribution of water among its components. In the laboratory, arbitrary decisions have to be made as to previous history. Length of curing period must be chosen; the specimen either is dried between the end of the curing period and the start of the freezing, or it is not dried; if it is dried, a decision must be made as to how much water to allow to escape, and then another must be made as to how long the specimen is to be soaked after drying and before freezing. Choices among such alternatives have much to do with the outcome of the test.

The test has become a more or less routine procedure expected to yield reliable indications of *relative* frost resistance. If a specimen of one kind suffers a given amount of deterioration from 150 cycles and another requires 300 to reach the same state, one might expect at least to have found which of the two would show superior frost resistance under field conditions. This is a reasonable expectation, provided that the test does not introduce conditions fundamentally different from those in the field. Some procedures now in use do introduce conditions fundamentally different from the most prevalent field conditions. The two most important discrepancies pertain to (1) rate of cooling and (2) length of continuous exposure to moisture.

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[11] This process is easily carried out in an imaginary experiment, but it would offer difficulty in a real one unless a bed composed only of coarse aggregates were used.

Rate of Cooling:

Field measurements indicate that concrete pavement seldom cools faster than 5 F per hr. Although laboratory cooling rates are not alike in different laboratories, many are upwards of 10 F per hr; cooling rates exceeding 100 F per hr have been reported. Using high rates of cooling seems to be regarded as a means of accelerating the natural process. Considerations set down in the two preceding sections, however, give reason to believe that the effect is not simply one of acceleration. It tends to give a distorted picture of relative frost resistance of different specimens of concrete; it gives an overload test rather than an acclerated natural process (**3**).

Data published by Valore (**23**) illustrate this excellently. He experimented with concrete specimens made with and without an air-entraining agent. Those without agent contained about 2.5 per cent air and the others 5.6 per cent; spacing factors were unknown. When these concretes (specimens P-27 and A-27) in a water-soaked condition were cooled 10 F per hr, their behaviors were similar; both cooled to 23 F without freezing, that is, they supercooled 9 per cent and then began to freeze. At the instant of first freeze, both dilated rapidly and then both *shrank* as temperature fell to −20 F.

Dilation during initial freeze indicated that the paste was not protected against the high initial rate of freezing of water supercooled 9 F. Occurrence of shrinkage following initial freeze indicated the paste to be protected, or nearly so, for low freezing rates. This was true even for the specimen not containing the air-entraining agent.

When, in a subsequent cycle, the same specimens were cooled at a higher rate (cycle 7), they no longer behaved alike. They were cooled slowly until they began to freeze and then at an average rate of 120 F per hr[12] to −20 F. During this cycle, there were only $3\frac{1}{2}$ instead of 9 deg of supercooling, and the rate of ice production during the initial freeze was correspondingly lower than it was in the first cycle. Initial dilation was likewise small. Up to this point, the two specimens behaved alike. But in the ensuing part of the cycle, when average cooling rate was 120 F per hr, the bubble-protected paste dilated much less than did the paste not so protected.[13]

These data indicate that the pastes in both plain and air-entrained concretes were protected equally well for low rates of ice production, even though void spacing factors were probably substantially different. But at high rates of freezing, bubble-protected paste appeared much the better, although cooling rate was too high even for it; it too, showed evidence of some dilation.

Thus, a substantial difference between rates of freezing constitutes such a fundamental difference as to produce opposite results and lead to opposite conclusions. A specimen frozen within the range of natural rates[14] might show immunity to frost damage, whereas when frozen at a high laboratory rate, it would be found vulnerable to frost action.

Laboratory tests as now conducted are liable to produce results not only different from those produced by nature, but also they are liable to produce disagreements between different laboratories. At the relatively high but different rates used in various laboratories, we should expect and do find most concrete to be vulnerable to frost. (As will be brought out further on, this may be due not only to high freezing rate but also to uninterrupted soaking.) Certain tests of air-entrained concrete have shown in a given laboratory that the void spacing factor required to hold the rate of deterioration below a certain limit is about 0.005 in., whereas in another laboratory using a lower freezing rate the limit appeared to be 0.01 in. (**24**). Thus a high freezing rate leads to a high estimate of the bubble concentration required for paste protection.[15]

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[12] The rate of cooling from 40 F to 20 F was about 400 F per hr.

[13] In fact, the bubble-protected paste did not show any dilation directly; it only failed to shrink as it should have. See discussion further on.

[14] Presumably, concrete is usually in contact with surface ice when it freezes, and thus probably does not supercool as it does in the laboratory. However, this question needs more investigation.

Such effects of freezing rate are to be expected when the principal cause of stress is hydraulic pressure. These remarks apply, therefore, to the effects of freezing in rock particles and in paste of ordinary porosity. On the other hand, if the paste is relatively dense, growth of capillary ice may be the principal source of stress. When this is so, fast freezing might lead to an opposite distortion, that is, to an *under*estimate of required bubble concentration rather than an overestimate. When dilation is due to crystal growth, length of time at low temperatures rather than rate of cooling may determine the amount of dilation, as already explained. Fast cooling is usually associated with short time at low temperature; hence, dilation due to crystal growth might be smaller the faster the cycle. The same may be true of control of osmotic pressure. No clear experimental demonstration of this possibility has yet appeared.

If the paste is protected by numerous bubbles against fast freezing, and if the aggregate is vulnerable, fast freezing may or may not produce distorted results. Highly permeable rock particles at a high degree of saturation freeze as overfilled closed containers and produce stress regardless of rate of cooling. But when rock particles contain macropores among the capillaries, rate of freezing might determine whether or not the rock can discharge excess water into its macropores without dilating or breaking. Likewise, rate of freezing might influence the performance of rocks in a partially saturated state if they are bigger than the critical size for freezing in the open while saturated.

Length of Soaking Period—Importance of Seasonal Drying:

While no condition in the field is typical, some kinds of conditions are more prevalent than others, and all can be placed in one or the other of the two following categories:

Category No. 1: Continuous soaking after completion of construction.

Category No. 2: Subject to occasional (at least seasonal) drying, at least on one side of the concrete member.[16]

Most laboratory procedures call for exposure belonging to category No. 1. All concrete is vulnerable to frost when it is so exposed, whether or not it contains entrained air and regardless of rate of freezing. Rock particles will become dilatant or not, depending on their physical characteristics, but paste will succumb when a significant number of air voids fill with water. The period of immunity may be very long; in laboratory tests, some specimens made with frost-proof aggregate remained sound for thousands of cycles, except for surface crumbling. Surface crumbling is due, probably, to the combined effect of leaching, filling of air voids, and freezing. Leaching of lime from the paste must increase its permeability and thus shorten the time required for the air voids, especially the smaller ones, to become water-filled.

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[15] Probably spacing factors normally produced with the amounts of entrained air now specified are smaller than is necessary for preventing natural freezing and thawing damage to the paste, but the factors are probably not smaller than necessary for control of scaling due to application of salts.

[16] Degree of drying is of course significant, too, but difficult to specify. For example, parts of a marine structure in the tidal range might be difficult to classify without suitable experimental investigation, though it would seem that 6-hr drying during ebb tides could hardly remove those parts from category No. 1; concrete takes up water much faster than it loses it by evaporation.

Most concrete contains rock particles that cannot be frozen in a water-soaked state with impunity. For such concrete, immunity to frost implies limited access to water and periodic drying; it implies exposure falling in category No. 2.

Notice particularly that exposures in category No. 1 offer no possibility of permanently frost-*proof* concrete. On the other hand, *exposures in category No. 2 present the possibility that some kinds of concrete are never damaged by freezing, even though they are subject to soaking and freezing every winter*. Thus, there is a fundamental difference between field exposures in category No. 2 and most, if not all, current laboratory exposures; for in the laboratory, freezing-and-thawing cycles are not interrupted once begun and, in most cases, thawing, if not also freezing, occurs in water.

Aggregate in air-entrained concrete is usually not critically saturated the first time concrete is frozen, but wetness of fall and winter tends to increase its water content. Under natural conditions falling in category No. 2, drying gives good concrete a reprieve every summer, if not oftener; aggregate particles that might have been approaching critical saturation at the end of winter are restored to a safe condition by summer sun and wind. Since most concrete is benefited by seasonal drying, one may question the correctness of using only one laboratory exposure and choosing the one falling in category No. 1. It seems more than likely that many concrete specimens destroyed in the laboratory test represent concrete that never could be damaged by natural freezing, no matter how many seasons of exposure.

Since most, if not all, laboratory procedures employ exposure falling in category No. 1, some correspondence might be expected between laboratory results and field performance under exposure in the same category. In a study of perhaps the best attempt to fulfill this expectation that has been made thus far, Kennedy and Mather (25) did not find the hoped-for correspondence. Comparing behavior in the laboratory with behavior of companion specimens exposed at Treat Island, Maine, where the exposure seems to be not far from that of category No. 1, they said: "The two exposures tend to accentuate different physical and chemical characteristics of materials, thereby leading to dissimilar results." These authors point out that differences in bond of paste to aggregate, differences in thermal properties, a possible swelling effect of sea water, and differences in air void spacing had to be considered in order to account not only for differences in field performance of air-entrained concretes made with different aggregates, but also to explain differences between field and laboratory performance of the same materials. Their analysis is ingenious and cannot be set aside. However, from the point of view developed in the present discussion, attention is drawn to probable effects of the difference in freezing rates. Laboratory specimens were cooled 36 F per hr. Field rates were lower most of the time.[17] Cycle for cycle, laboratory tests proved to be the more severe except for one kind of coarse aggregate.

Had the laboratory freezing rate not been so high, the Treat Island experiments might have shown whether or not a laboratory test can predict field behavior under exposure in the same category. With the laboratory test actually used, it is probable that the paste in some specimens was not fully protected against the effect of freezing at 36 F per hr, and that degrees of protection were not equal among concretes made with different aggregates. On the other hand, it is possible that pastes were fully protected against freezing rates occurring at Treat Island. If these suppositions are true, frost action in the laboratory was a more complex process than it was on Treat Island because it involved not only effects of freezing in aggregate particles, but also effects of paste dilation, whereas on Treat Island paste dilation may not have been involved. The point is that, whether or not the suppositions are true in this particular case, at least some of the variations noted could be accounted for in terms of freezing rates.

Need for Modifications:

Other features of present procedures could be questioned, but perhaps what has been said is enough to show that interpretation of results from current tests offer serious difficulties. Results that might apply to continuously wet exposure are clouded by distortions due to high freezing rates. Benefits of occasional drying are not evaluated in laboratory tests.

Interpretation of laboratory tests based entirely on relative rates of deterioration also has inherent limitations. Once disintegration starts, it continues at a rate determined by an exceedingly complex array of variables, some of which are related to properties of concrete and some to environment; actual rate of disintegration may depend as much on peculiarities of a given situation as on concrete characteristics. Since possible situations are numberless, it is not likely that the rate of disintegration shown in the laboratory could ever be a satisfactory basis for predicting rate of disintegration in the field, and, in fact, no reliable relationship has yet been demonstrated. Perhaps the best that has been done is to identify by laboratory behavior certain aggregates known to have performed badly in some situations, and to demonstrate the efficacy of entrained air. Wuerpel (30) expressed the views of many when he said: "There is no formula known to the author for translating laboratory cycles into freezing cycles of nature." Perhaps it can be agreed, without undue pessimism, that no such formula will ever be found.

PROPOSAL FOR MODIFIED TEST PROCEDURE

To surmount the difficulties discussed in preceding pages seems to require a change in point of view. It should first be recognized that concrete has no intrinsic property that is, *per se*, frost resistance or durability and, therefore, that it appears futile from a basic viewpoint to attempt to measure frost resistance or durability. Intrinsic properties that determine behavior under a given set of circumstances can, however, be determined. Such properties include strength, permeability, porosity, pore size distribution, stress-strain-time characteristics, thermal characteristics, and others. With quantitative knowledge of these characteristics, behavior could conceivably be predicted under any given set of circumstances. But this approach, too, presents difficulties. The heterogeneity of concrete being what it is, obstacles are probably insurmountable. Although knowledge of properties of different components of concrete and knowledge of mechanisms of frost action are essential to an intelligent approach to the problem, it still seems necessary to stay with the original approach, which is that of making some sort of observation on the behavior of specimens of concrete under controlled conditions.

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[17] Bryant Mather, Chief, Special Investigations Branch, Waterways Experiment Station, U. S. Army Corps of Engineers, very kindly gave the author the following statement:

"Freezing occurred only during the winter months or during only about 100 of the annual 700 cycles of submergence and emergence. When freezing did occur, it was most frequently in an air temperature only a little below the freezing point, and hence the cooling rate was very low. The lowest air temperature on record at Treat Island is −23 F; under such conditions a small specimen emerging from sea water at 40 F might cool through the range 30 F to 15 F at a rate equal to or higher than 36 F per hr. During the five winters 1950 to 1955, only 35 cycles involving temperatures at the center of a 6 by 6-in. specimen of 10 F or lower were recorded, the lowest temperature being −8 F, recorded on two cycles in the same day, 13 February 1954. The cooling rate for this cycle, between 30 F and 15 F, was about 14 F per hr."

The behavior of water-soaked concrete while it is being cooled to temperatures below the normal freezing point is fundamentally the point of concern. Some kinds of concrete in some situations behave approximately as metallic solids do; they contract and expand uniformly with falling and rising temperature. With other concretes or situations, departures from such normal behavior may occur. The most useful test might be one which would tell whether or not concrete is in a condition to behave properly on cooling and, if it is, to tell how long it will remain in that condition while exposed to water and periodic freezings. Such information cannot be obtained by using a method that forces disintegration and then produces only a measure of the rate of disintegration. It *might* be obtained by suitable measurements of length change while concrete is being cooled.

Above the temperature at which freezing starts, the relationship between volume and temperature should be nearly linear.[18] After freezing begins, the relationship should change; if paste is properly protected with bubbles, and if water content of the aggregate is below the critical saturation point for that aggregate, contraction per degree should *increase* because of shrinkage superimposed on thermal contraction. Only in dry concrete should the relationship be linear over the whole range. (Valore (23) was probably the first to demonstrate some of these facts. However, interpretation of his data is complicated by effects of supercooling and possibly by critical saturation in the aggregate.) Improper behavior is for the specimen to contract normally until freezing begins and then to dilate rather than shrink with further decrease in temperature.

Proposed Procedure:

Length measurements can be used to tell whether or not at any given time a specimen is vulnerable to frost action. If it shrinks normally in the freezing range, it is immune; if it dilates, it is not immune—the process that eventually causes disintegration has begun. A suggested procedure for detecting immunity or lack of it, and for estimating relative rate of disintegration after the period of immunity is past, is outlined in the following paragraphs.

1. Make three prisms or cylinders of air-entrained concrete using materials in

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[18] While a body of hardened paste is changing from one temperature to another, contraction is not linear, and the lower the porosity of the paste, the greater the departure from linearity (**4**). In concrete, linear contraction of rock particles masks the nonlinearity of paste to such an extent that contraction of concrete usually appears linear at temperatures above the freezing range.

question. Specimens should be big enough to permit using the same aggregate gradation that will be used in the field; no large sizes should be discarded or crushed. Except when there is reason to do differently, use a mix requiring $5\frac{1}{2}$ gal per sack ($w/c = 0.49$ by weight) in a properly formulated mix. The void spacing factor should be under 0.01 in. and should be known.

2. Cure the specimens under standard moist conditions for two weeks and then store them in laboratory air for two additional weeks.[19] Finally, store them in water. Keep track of changes in weight and length during the whole period.

3. After the specimens have been in water for two weeks, equip each with a suitable strain meter and cool them about 5 F per hr from water-bath temperature to 0 F. Hold the low temperature overnight. Prevent drying during cooling. Record changes in length and temperature of the specimen continuously, preferably automatically.

4. If the specimens dilate during the period of freezing, the first part of the test is over; they have shown less than two weeks of frost immunity. If they show no dilation, they have remained immune during two weeks of soaking. Return them to water storage and repeat the test two weeks later, and so on, until the longest safe period of soaking has been found.

5. After the length of the period of immunity has been measured, the specimens may be subjected to several successive cycles of freezing and thawing in water to establish the characteristic rate of dilation under laboratory conditions. Dilation usually increases exponentially—that is, $D = A^n$, where D is the amount of *permanent* dilation, n is the number of cycles after dilation begins, and A is a constant characteristic of the specimen. Evaluation of A from experimental data should provide a convenient expression for characteristic rate of dilation.

Discussion of Proposed Procedure:

The main purpose of this test is to detect the time when some part of the aggregate in a specimen of air-entrained concrete has absorbed more water than it can contain during freezing. The length of the period of immunity is the primary measure of frost resistance—the unit might be one week. The rate of dilation after dilation begins is the secondary measure.

The second part of the proposed test was anticipated by Valore (**23**) and by investigators at the U.S. Bureau of Reclamation laboratories. Referring to various indications of his data, Valore said: "Should further experimentation verify these implications, the possibility of predicting durability on the basis of measurement of transient or residual strain for one or two cycles of freezing and thawing suggests itself." Higginson and Kretsinger (**28**) found a fair correlation between rate of disintegration in the freezing-and-thawing test and dilation during a single cooling as reported by Mitchell (**27**).

The suggested freeze test involves two periods: (1) a period during which temperature falls steadily, and (2) a period of practically constant low temperature. During the first period, stress, if any, may be due primarily to hydraulic pressure in the paste or in the aggregate or in both, but the intention is that paste should always be amply protected with bubbles. Any stress developed during the constant temperature period would be due to growth of capillary ice or to osmotic pressure or to both. Thus, the proposed procedure is designed to detect a tendency to dilate, whatever the mechanism of that dilation. It is not intended to be an accelerated natural process. Rates of absorption are those that occur naturally at laboratory temperature.

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[19] This period of drying is that now used by some laboratories with prisms of 3-in. cross-section. If larger specimens are used, some longer period of drying giving a comparable state of dryness should be used. Ultimately, this feature of the test should be based on studies of field conditions.

A question needing experimental investigation is whether or not, *in the absence of dilation*, absorption rate is increased significantly by freezing and thawing. The procedure outlined is based on the assumption, or rather hope, that freezing has little effect until after dilation begins. If the contrary is true, an arbitrary choice must be made as to number of cycles of freezing and thawing to add to the suggested one freeze every two weeks.

Another question is whether the end point should be the first occurrence of *permanent* dilation after thawing or occurrence of dilation (rather than shrinkage) during the freeze, even though dilation may be small and transitory. The first alternative requires a control of some sort, so that dilation due to freezing can be distinguished from volume increase due to other causes. The second alternative is attractive for it requires no control; gradual swelling during soaking would not have any bearing on interpretation of behavior.

If it can be carried out as suggested, the primary part of the test should be less laborious and less costly than the present freezing-and-thawing test. When testing concrete for exposures in category No. 2 (occasional drying), a period of immunity during, let us say, 16 weeks of continuous exposure to water should assure immunity during any winter season. On this basis, one setup able to handle three specimens at a time would enable one operator to test at least ten different materials in a period of about 18 weeks without handling more than three specimens a day. If any materials fail to run the full course, testing capacity would be increased. Of course, if the concrete in question is to be used continuously wet (category No. 1), the period of test would have to be extended until dilation begins, however long a time that might be, if a measure of immunity is to be obtained.

The proposal just outlined is not the only possibility for measuring the period of immunity. Details specified are intended only to be suggestive. The period of drying might be different for different specimen sizes, as required to establish an intended degree of dryness. The degree of dryness at the start of the test should ultimately be based on suitable studies of moisture content in the field—of pavements, for example, on various types of subgrades at the end of summer.

It may be possible to use some present freezing-and-thawing procedures. An example may be drawn from data reported by Blackburn (29). Freezing-and-thawing tests using a comparatively moderate freezing rate (11 F per hr) were reported. Among various kinds of air-entrained concrete were some made with three different coarse aggregates ("good," "poor," and "bad") which had been cured two weeks and dried two weeks before being subjected to daily freezings. Specimens stood in $\frac{1}{2}$ in. of water during freezing and thawing. Effects of freezing and thawing were reported in terms of "dynamic *E*." Three different air contents were used, one or more of which probably gave full protection to the paste.

All specimens, bubble-protected or not, showed a drop in dynamic *E* of about 5 per cent during the first cycle or two of freezing and thawing; thereafter dynamic *E* remained practically constant or showed a slight gain for 80 or more cycles of freezing and thawing. The initial drop probably did not signify frost damage but some change in conditions affecting resonant frequency. The end of the period of immunity can be considered to occur at the time when dynamic E begins to drop below the general level established after the first cycle or two.

On this basis, the results show the "good" aggregate to have remained safe throughout a period of 150 freezing-and-thawing cycles, the longest time reported being a period of 25 weeks. Hence, this concrete would be rated as being immune to frost for at least 25 weeks. It should remain unharmed by freezing from one summer to the next for exposures in category No. 2.

With the aggregate called "poor," deterioration began after 80 cycles, about 13 weeks. With the aggregate called "bad," no drop in dynamic E was indicated during the whole period of 150 cycles, 25 weeks. (The ratings "good," "poor," and "bad" were probably based on field studies of nonair-entrained concrete.)

Use of dynamic E to detect the end of the period of immunity is probably inferior to a measure of dilation. With specimens cured only two weeks before beginning the test, some increase in E is to be expected from further hydration of cement. Thus, the time at which dynamic E begins to fall is the time when its possible increase due to further hydration is not so great as the decrease due to damage from freezing. Moreover, since it is measured after thawing, E tells only when dilation gets bad enough to produce permanent damage. A direct measure of dilation produced during freezing might be a more delicate and reliable indicator of the state of saturation of the aggregate. This is a matter to be settled by suitable experiments.

If, as assumed in the proposed procedure, freezing has nothing to do with the rate of absorption during the period of immunity, the cost of operating the freezer during the 13 to 25-week periods of immunity could have been avoided. That is why only fortnightly checks of the state of test specimens is suggested for the new procedure.

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PRESSURE DISTRIBUTION ALONG FRICTION PILES*

By L. C. Reese[1] and H. B. Seed[2]

The supporting capacity of a friction pile driven into saturated clay appears to be determined mainly by the strength of the clay surrounding the pile. When the pile is first driven the clay is remolded and the supporting capacity of the pile may be quite low. However, the pressures developed in the clay as a result of its displacement by pile driving cause the remolded clay to consolidate, with a corresponding increase in strength. This increase in strength, which develops over a number of days following the driving of the pile, is normally accompanied by an increase in supporting capacity of the pile. The final supporting capacity of the pile depends therefore on the magnitude of the pressures developed in the soil surrounding the pile, and the rate of increase in supporting capacity would be expected to depend on the rate at which the excess pore water pressure in the clay surrounding the pile is dissipated.

This paper describes an investigation of the pressures developed at the wall of a pile driven into clay and presents theories for the analysis of these pressures.

Several 6-in. diameter pipe piles, 20 to 22 ft long, were driven about 15 ft into a stratum of soft, saturated clay. Electric strain gages were installed on one pile to measure load and pressure distribution along the pile. This pile was test loaded soon after driving and a number of times thereafter. Total pressures and pore-water pressures, caused by the action of the soil against the pile wall, were measured at several points along the pile length during the pile driving and during the load-test period.

Several borings were put down in the test area, and undisturbed soil samples were obtained. Soil tests were made to establish the relationships between strength and water content for clay unaffected by pile driving, for clay next to a pile which had been in place 1 day, and for clay next to a pile which had been in place 30 days. The soil test results were interpreted to determine the effect of pile driving on the clay and the resistance of the clay to movement of the pile.

In addition, the pressures developed between the pile and soil as a result of driving an adjacent pile several feet away were recorded and analyzed.

THEORIES RELATING TO PRESSURES ALONG FRICTION PILES

In order to make an accurate analysis of the performance of a friction pile driven into clay, it would be necessary to determine the properties of the partially remolded soil surrounding the pile and the rate of change of these properties with time. This would require a knowledge of the extent to which the clay is disturbed by pile driving, the rate of dissipation of the excess hydrostatic pressure developed in the clay, and the

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change in water content or effective pressure in the clay accompanying the decay of pressure in the pore water. The strength characteristics of the soil could then be determined from the strength *versus* water content relationship for the soil.

At the present time not all of these factors can be evaluated. Little is known of the degree of disturbance of soil caused by pile driving, and the mechanics of the consolidation process around a pile is obscure. As a first step towards the ultimate goal, theories have been developed to determine the pressures in the soil surrounding a pile immediately after driving and the rate of decay of the pressures in the pore water. Although a complete theory for the analysis of pile performance is not yet available, the development of a theoretical method of determining the rate of decay of pore water pressure may have immediate practical applications in that it will enable an estimate to be made of the time required for a pile to develop its maximum supporting capacity.

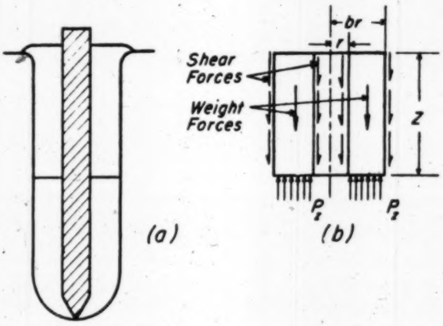

FIG. 1.—Analysis of Pressures in Saturated Clay During Pile Driving.

Pressure Against Wall of a Cylindrical Pile During Driving Into Saturated Clay:

A simplified theory for determining the total pressures acting against the wall of a pile that is being driven into saturated clay can be developed by assuming that the displaced soil behaves essentially as a viscous fluid. As a further approximation, it can be assumed that the viscous fluid moves upward near the pile in the form of a hollow cylinder, as is shown in Fig. 1. The pressure in the fluid at any depth z can then be obtained by equating the total upward pressure on the column of fluid above depth z to the downward forces on this column due to the shearing resistance of the fluid acting on the inner and outer cylindrical surfaces and the weight of the fluid.

If the inner radius of the cylinder is r and the outer radius is br, then:

$$p_z\pi(b^2r^2 - r^2) = \tau_i \times 2\pi rz + \tau_o \times 2br\pi z + \gamma\pi(b^2r^2 - r^2)z$$

and

$$p_z = \left[\frac{2\tau_i + 2b\tau_o}{r(b^2 - 1)} + \gamma\right] z \ldots\ldots (1)$$

where:

p_z = pressure in the fluid at depth z,

τ_i = shearing resistance on inner cylindrical surface,

τ_o = shearing resistance on outer cylindrical surface, and

γ = unit weight of soil.

In order to obtain the pressure acting on the pile wall, the assumption is made that the viscous fluid exerts the same pressure in all directions. If the shearing resistance of the remolded soil is low, this assumption is justified.

The distribution, between pore-water pressure and effective pressure, of the total pressure on the clay during and immediately after driving can be determined from a consideration of the two main causes of the pressure changes. First, the remolding of the soil will result in an increase in pore-water pressure and a decrease in effective pressure due to the fact that the soil is no longer consolidated under the overburden pressure. Secondly, there is an increase in the pore-water pressure due to displacement of the soil during pile driving.

The change in pressure due to remolding can be determined from the effective pressure *versus* water content relationships of undisturbed and remolded soil. These relationships can be obtained from laboratory consolidation tests. Typical curves for a remolded and undisturbed soil are shown in Fig. 2. If the soil is initially consolidated, the water content of the undisturbed soil on curve *A* will correspond to the effective overburden pressure. If on the other hand the soil is completely remolded, the effective pressure in the remolded soil can be obtained by reading the pressure from curve *B*, corresponding to the water content of the undisturbed soil. For soil which is disturbed or partially remolded due to pile driving, a curve such as curve *C* can be used instead of curve *B*.

The consolidation test data provide a means for determining the pressure changes due to the effect of remolding, but account must be taken of the pressure changes due to the soil displacement caused by pile driving. In this respect, it can be assumed that any additional pressure due to soil displacement goes into the pore water. This assumption is also made in the development of the theory of consolidation.

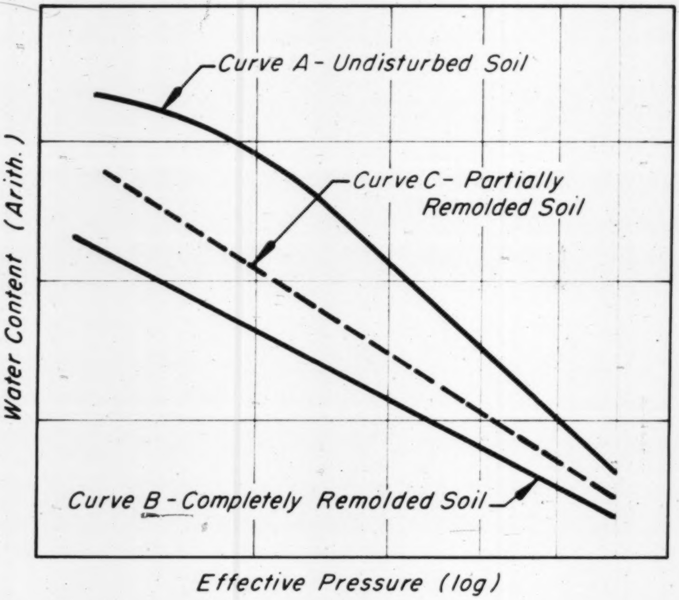

FIG. 2.—Effective Pressure *versus* Water Content Relationships for Undisturbed and Remolded Soil.

Thus, the following procedure may be used to determine the pressures at any point on a pile wall immediately after the pile has been driven into clay:

1. Obtain the total pressure by Eq 1,
2. Obtain the effective pressure from consolidation test data, and
3. Obtain the pore-water pressure by subtracting the effective pressure from the total pressure.

Decrease in Excess Hydrostatic Pressure with Time:

If a single cylindrical pile is driven rapidly into a uniform stratum of saturated clay, the displacement and remolding of the clay will result in the development of excess hydrostatic pressures in the pore water in the soil around the pile. The excess hydrostatic pressure will decay rapidly at points near the water table, by movement of water principally in the vertical direction. At points some distance below the water table, horizontal movement of the water has been observed to occur (**1**).[3] If it is assumed that all flow takes place in horizontal directions, the pressures may be examined in a thin slice of soil perpendicular to the pile axis.

The exact mathematical model for the rate of decay of the excess hydrostatic pressure around a friction pile is obscure. However, the problem is somewhat analogous to the diffusion of heat in a homogeneous medium and, as an approximation, can be assumed to follow similar laws. The heat-flow analogy has been applied to another problem in soil mechanics, with a rigorous justification for its use—to the problem of one-dimensional consolidation, which would occur when a stratum of saturated clay is subjected to an increment of vertical pressure causing initially a uniform increase in the pore-water pressure in the stratum (**2**). The excess hydrostatic pressure is relieved by a linear flow of water to the upper and lower boundaries of the soil stratum, and its variation with depth and time is expressed by the differential equation:

$$c_v \times \frac{\partial^2 u}{\partial z^2} = \frac{\partial u}{\partial t} \quad \ldots\ldots\ldots\ldots (2)$$

where:

u = excess hydrostatic pressure,
t = time,
z = vertical coordinate, and
c_v = coefficient of consolidation.

The coefficient of consolidation in one-dimensional consolidation is a function of the coefficient of permeability of the soil, the unit weight of water, the void ratio, and the pressure-void ratio relationship of the soil. This coefficient has the units of Length^2/Time and can be determined with reasonable accuracy from laboratory tests.

The one-dimensional consolidation solution is completely analogous to the solution for the diffusion of heat in a solid bounded by two parallel planes. The solid, or slab, is heated initially to some uniform temperature throughout; then its surfaces are held at some lower temperature, and the heat flows linearly from the slab to the surfaces.

The heat diffusion problem, which is similar to the decay of excess hydrostatic pressure around a driven pile, concerns the flow of heat in the region bounded internally by a cylinder. The walls of the cylinder are considered to be insulated so that no heat can flow across this boundary. The differential equation describing the flow is the diffusion equation using polar coordinates and circular symmetry:

$$K\left[\frac{\partial^2 u}{\partial r^2} + \frac{1}{r}\frac{\partial u}{\partial r}\right] = \frac{\partial u}{\partial t} \quad \ldots\ldots (3)$$

where:

u = temperature,
r = radial coordinate,
t = time, and
K = diffusivity constant.

The solution of the problem has been presented by Carslaw and Jaeger (**3, 4**). An instantaneous surface source of heat of strength Q is considered to act over the surface $r = c$ at time $t = 0$ in a region extending from $r = a$ to $r = \infty$, as is shown in Fig. 3. The boundary, $r = a$, is insulated so that no flow of heat can occur across it. The quantity of heat liberated per unit length of the cylinder is $Q\rho c_1$ where ρ and c_1 are the density and specific heat of the material. For these conditions,

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[3] The boldface numbers in parentheses refer to the list of references appended to this paper, see p. 1180.

$$u = \frac{Q}{2\pi} \times \int_0^{\infty} e^{-Kv^2t} \times X \quad \ldots\ldots (4)$$

and

$$X = \frac{[J_1(va)Y_0(vc) - J_0(vc)Y_1(va)] \times [J_1(va)Y_0(vr) - J_0(vr)Y_1(va)]}{J_1^2(va) + Y_1^2(va)}\, v\,dv$$

where:

u = temperature,
Q = strength of instantaneous surface source,
K = diffusivity constant,
t = time,
v = variable,
J_0 = Bessel function of first kind of order zero,
J_1 = Bessel function of first kind of order one,
Y_0 = Bessel function of second kind of order zero, and
Y_1 = Bessel function of second kind of order one.

This solution may be assumed to describe the decay of excess hydrostatic pressure around a pile, which has been driven rapidly into position, if the terms of the equation are redefined as follows:

u = excess hydrostatic pressure, lb per sq ft,
Q = strength of instantaneous surface source, lb,
K = constant sq ft per sec, and
t = time, sec.

The heat-flow problem and the pile problem, although similar in several respects, are not completely analogous. For example, the instantaneous surface source in the pile problem cannot be satisfactorily defined in physical terms. However, there is enough similarity in the two processes to justify the use of the heat-flow solution as a first approximation for the solution of the problem of the decay of excess hydrostatic pressure around a driven pile.

For the case of the rapidly driven pile, it seems logical to assume that the instantaneous surface source of pressure to strength Q is applied at the pile wall. If, by some means, values can be obtained for Q and K, the solution of Eq 4 can be obtained. The integration would have to be done using a numerical process and would be tedious. However, a simple solution may be obtained for the special case when Kt is large.

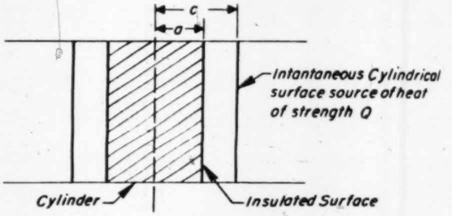
c
a
Intantaneous Cylindrical surface source of heat of strength Q
Cylinder
Insulated Surface

FIG. 3.—Section Through Infinite Mass Perpendicular to Axis of Cylinder.

Examination of Eq 4 shows that for large values of Kt values of v must be small for the integral to have magnitude; otherwise the exponential term would approach zero. Therefore, for very large values of t, the integral can be approximated by its value for small values of v, at least insofar as the term

$$\frac{[J_1(va)Y_0(vc) - J_0(vc)Y_1(va)]\,[J_1(va)Y_0(vr) - J_0(vr)Y_1(va)]}{J_1^2(va) + Y_1^2(va)}\, v$$

is concerned. Now, for small values of x (6):

$$J_0(x) \sim 1; \qquad J_1(x) \sim \frac{x}{2};$$

$$Y_0(x) \sim \frac{2}{\pi} \times \log \frac{x}{2};$$

$$Y_1(x) \sim -\frac{2}{\pi x}.$$

Hence, the terms involving $Y_1(va)$ dominate the expression above and it approaches very closely the value v. Substituting this value in Eq 4:

$$u \sim \frac{Q}{2\pi} \times \int_0^\infty e^{-Kv^2t}\, v\,dv = \frac{Q}{4\pi Kt} \ldots (5)$$

This corresponds to the eventual decay of pressure uniformly throughout the whole region exterior to the pile, independently of the radius of the pile and the location of the instantaneous source. Soon after the source has been applied, there will be a rapid decay of pressure in the vicinity of the source. This decay will proceed until at some later time all indication of the original distribution has effectively disappeared. It is for this later period that the simplified equation is valid, and the equation will give pressures at the pile wall and in the region exterior to the pile wall.

Equation 5 would appear to be the desirable solution from the practical standpoint since it can be used to determine the time required for the decay process to be virtually completed. Since the ultimate bearing capacity of a pile is not likely to be realized until the excess hydrostatic pressure around the pile has been dissipated, the resulting solution will be a determination of the time required for the pile to attain its ultimate bearing capacity.

PILE TESTS, SOIL TESTS, AND PRESSURE MEASUREMENTS

Location of Tests and Soil Conditions:

The pile tests were conducted at a site adjacent to the San Francisco-Oakland Bay Bridge on the east side of San Francisco Bay. The soil conditions at this site (Fig. 4) consisted of about 4 ft of fill, 5 ft of sandy clay, and then a layer of organic silty clay, containing shells, known locally as "bay mud," which extended to at least 30 ft below the ground surface. The water table was about 4 ft below the ground surface.

The site was chosen after extensive field tests had shown the soil conditions in the area to be relatively uniform. The relative positions of the piles and borings at the test site are shown in Fig. 5.

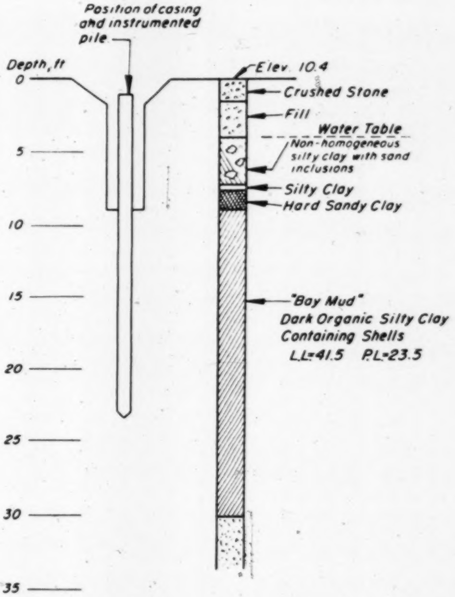

FIG. 4.—Soil Profile.

In order to eliminate the effects of the upper 9 ft of nonhomogeneous soil on the supporting capacity of the instrumented pile, a 12-in. diameter casing was installed to a depth of 9 ft and the soil inside the casing was removed. The pile was then driven into the silty clay.

Results of Soil Tests:

The properties of the undisturbed soil into which the piles were driven were determined by a comprehensive series of tests on samples taken with a piston type sampler in Shelby seamless steel tubes 30 in. in length and 2.87 in. in diameter. The average of several determinations of the unit weight of the undisturbed silty clay was 112 lb per cu ft, and average values for the Atterberg limits were: liquid limit = 41.5, plastic limit = 23.5.

Unconfined compression tests were performed on 23 samples and consolidation tests on 4 samples. In addition, tests were performed on remolded samples of the soil. Many of the samples contained a fair proportion of shells, which complicated the trimming of specimens for compression and consolidation tests. Typical results obtained in consolidation tests on samples of the undisturbed and remolded soil are plotted in Fig. 6.

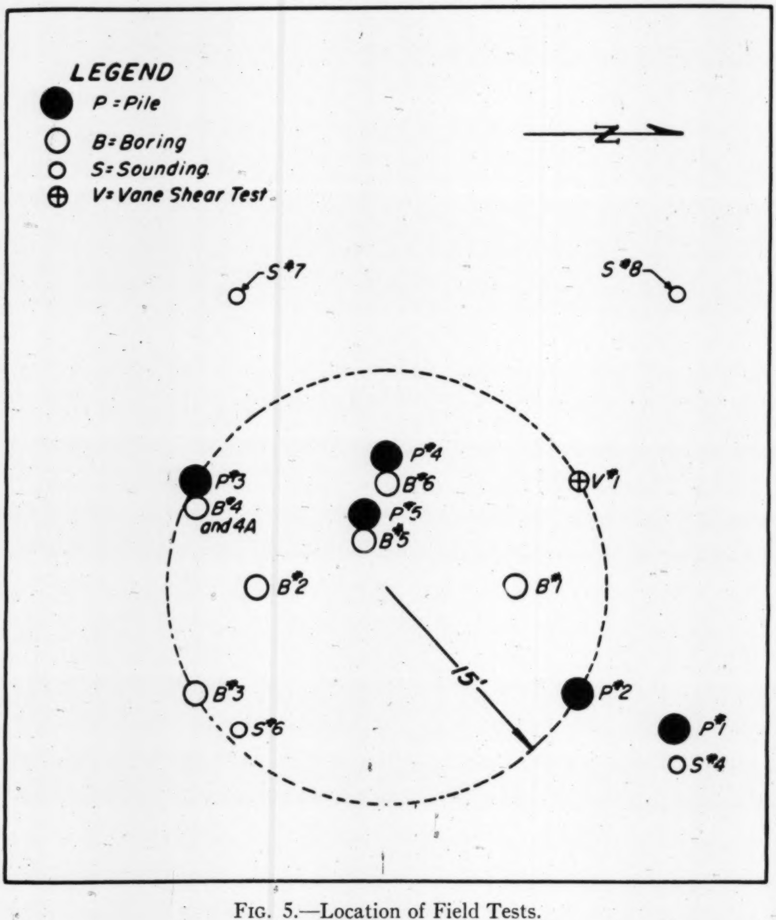

FIG. 5.—Location of Field Tests.

In order to determine the effects of pile driving on the soil adjacent to a driven pile, samples were taken next to a pile which had been in place for one day and next to a pile which had been in place for 30 days. Unconfined compression tests were performed on these samples. Since at any particular time the unconfined compression strength appeared to be approximately constant with depth, average values were used to determine the change in strength with time. Analysis of the data (5) indicated that the average unconfined compression strength of the soil adjacent to the pile increased from a value of 0.14 kg per sq cm at the time of driving to 0.3 kg per sq cm after 1 day, and to 0.37 kg per sq cm after 30 days.

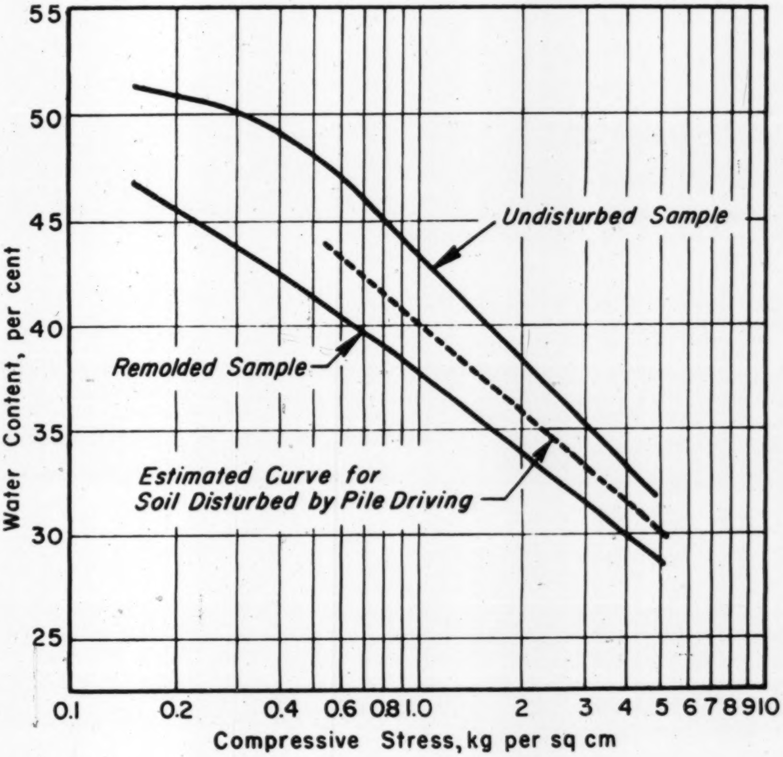

FIG. 6.—Consolidation Test Data for Undisturbed and Remolded Soil.

Pressure Gages:

Pore-Water Pressure Gage.—The design of a suitable gage for measuring the pore-water pressure in the soil near the wall of a pile is complicated by the fact that, although the gage must be sufficiently sensitive to provide quantitative values of the changes in pressure, it must also operate with a minimum flow of water from the soil.

The design of a small pore-water pressure gage, making use of electrical strain gages on a metal diaphragm, has been described by Boiten and Plantema (6). Other small diaphragm-type gages of this sort have been built at the David Taylor Model Basin (7) and at the Engineering Materials Laboratory of the University of California.

The sensitive element of the gage is a thin, circular diaphragm, which is fixed at its edges and on which water pressure is allowed to act. The diaphragm deflects

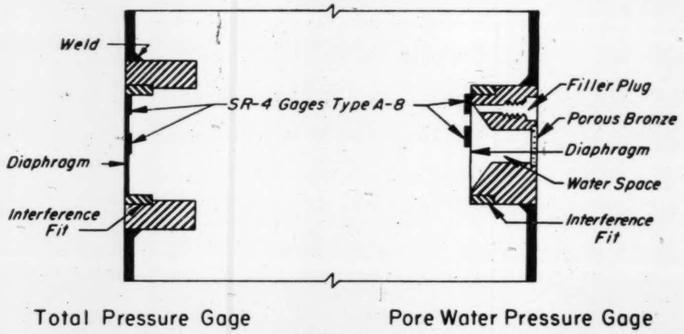
Weld
SR-4 Gages Type A-8
Diaphragm
Interference Fit
Filler Plug
Porous Bronze
Diaphragm
Water Space
Interference Fit
Total Pressure Gage
Pore Water Pressure Gage

FIG. 7.—Typical Section Through Pile Showing Pressure Gage Construction.

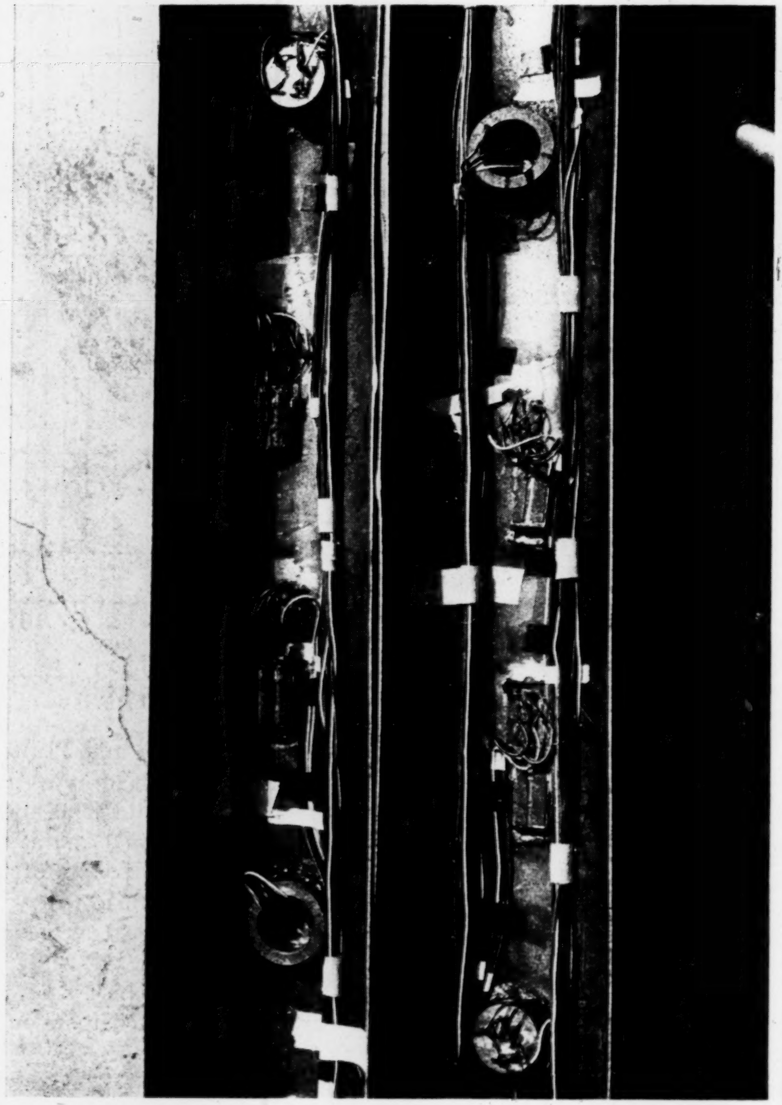

FIG. 8.—View of Instrumentation.

and the consequent strains are measured by SR-4 electric strain gages and recorded on a strain indicator. By previous calibration, the strains are translated into pressures. From the instrumentation standpoint, an advantage of this type of gage is that both tensile and compressive strains are produced, and these strains may be added by using an external bridge to increase the sensitivity of the measurement.

The details of the pore-water pressure gage used in this investigation are shown in Figs. 7 and 8. A short piece of thick-walled tube was welded into a hole cut into the wall of the pile; the outside of the tube was ground to conform to the shape of the pile and was covered with a porous bronze disk. The inside end of the tube was machined with close tolerance to provide a water-tight interference fit between the tube and the diaphragm. Water passed through the porous bronze disk and acted against the diaphragm. The diaphragm was made of high-strength stainless steel, with the diaphragm thickness being varied according to the pressure which was expected to develop in the pore water along the pile length. A filler plug was provided so that the space between the porous bronze and the diaphragm could be completely filled with water just before the pile was driven. The gage was sufficiently small so that after installation it had no appreciable effect on the surface contour of the pile.

Before the pile was driven, the gages were calibrated by applying a known pressure around the outside of the pile. pressure was applied in increments and the response of the gages for each increment was noted. A typical calibration curve for a pore-water pressure gage is shown in Fig. 9.

Total Pressure Gage.—A diaphragm-type gage was also used to measure the total pressure developed at the wall of the pile. For these gages, also, the deflection should be small in order to avoid arching of the soil across the gage. In this respect an advantageous feature was that most of the initial deflection took place during driving when the soil around the pile acted as a viscous fluid. After driving, the pressures diminished and the resulting outward deflection of the diaphragm caused no trouble.

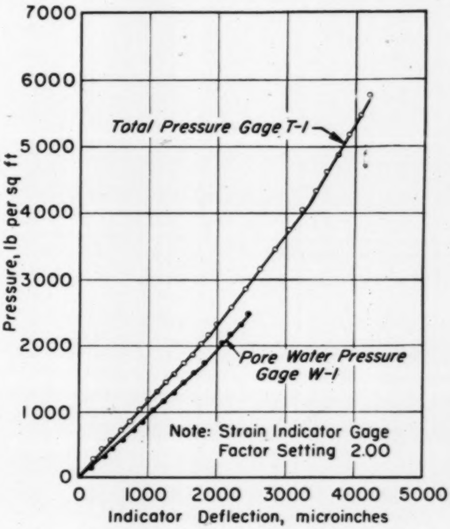

FIG. 9.—Typical Calibration Curves for Pressure Gages.

The details of the design of the total pressure gages are shown in Fig. 7. The diaphragms used were similar to those used in the pore-water pressure gages, with the thickness being varied according to the total pressure anticipated. The $1\frac{1}{2}$-in. diameter flat surface of the gage caused a slight change in the outside contour of the pile. However, the edges of the gage were faired into the contour of the pile so that there were no abrupt changes in section.

The total pressure gages were also calibrated by applying known pressures to the wall of the pile before the pile was driven. A typical calibration curve is shown in Fig. 9.

Description of Test Piles:

The piles used in the investigation were made from 6-in. diameter spiral welded steel pipe, No. 14 gage, and were fitted with conical driving points. The pile to be instrumented was cut in halves lengthwise so that the gages could be installed. Six total pressure gages and six pore-water pressure gages were installed at intervals of 2 ft along the pile. A view of the instrumentation prior to rejoining the pile halves by welding is shown in Fig. 10.

Preparations had been made to reduce welding temperatures, which were expected to develop at the gage locations when parts of the pile were welded together, but no special precautions were necessary. The halves of the pile were first connected by tack-welding, and then 4-in. beads were run at intervals of 3 or 4 ft until welding was completed. The conical point and the uninstrumented

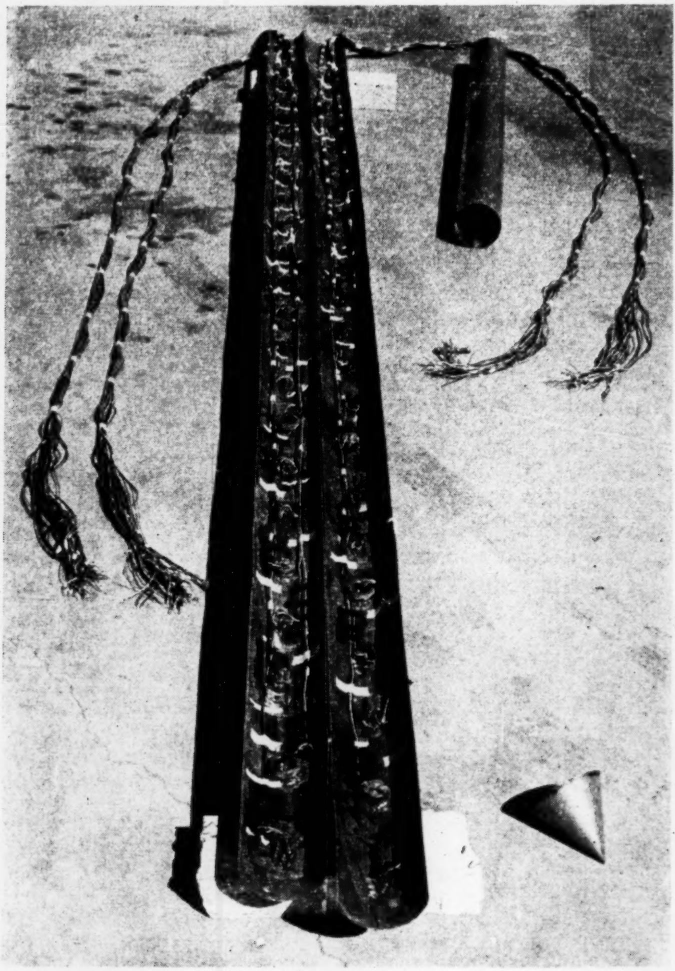

FIG. 10.—Instrumented Pile Prior to Assembly.

top section shown in Fig. 10 were welded on to complete the assembly. A view of the completed pile just prior to driving is shown in Fig. 11.

Air pressure was applied to the inside of the pile and the welds were carefully checked for leaks. A detergent solution was useful in finding small holes in the welds.

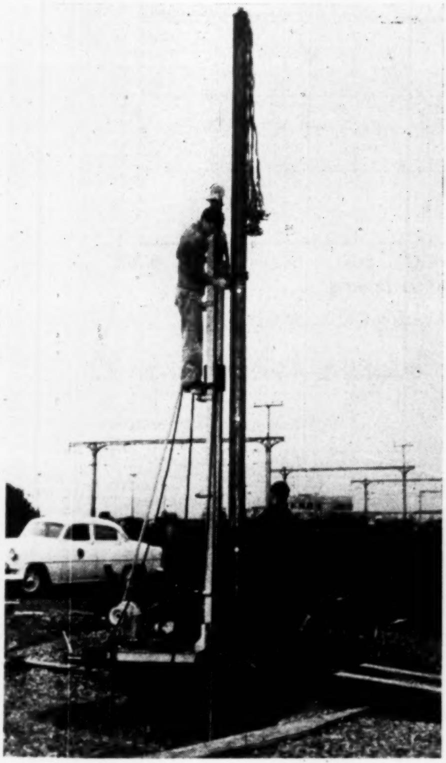

FIG. 11.—Pile Prior to Driving.

The instrumented pile was lowered to the surface of the clay at the bottom of the casing and driven into the clay using a 150-lb drop hammer. The soil profile, the arrangement of the casing, and the final position of the pile are shown in Fig. 4.

Several gages were damaged when the instrumented pile was driven, but a sufficient number of gages remained intact so that data were successfully obtained from all types of measurements.

After the pile was driven to position, large changes were found to be taking place in the pressures at the pile wall. These pressures were read as rapidly as possible, and at the same time the loading apparatus was being prepared for the first load test. It was assumed that pile loading would affect the pressure measurements, but it was hoped that this effect would be small if the pile settlement was kept to a minimum. Readings during a preliminary load test and during several subsequent load tests indicated that loading caused little if any permanent effect on the pressure gage readings.

TABLE I.—PRESSURES DURING AND IMMEDIATELY AFTER DRIVING.

Pile Penetration Below Ground Surface, ft	Depth Where Pressure Was Measured, ft	Distance from Pressure Gage to Bottom of Casing, ft	Total Pressure, lb per sq ft	Pore-Water Pressure, lb per sq ft
11.4	10.4	2.4	1100	...
12	11	3.0	...	575
13	12	4.0	2740	860
15	14	6.0	3290	1620
15	12	4.0	1870	...
17	16	8.0	3290	2580
17	14	6.0	2040	...
19	18	10.0	3790	...
20	17	9.0	2900	...
20	19	11.0	...	3430
21	20	12.0	4180	...
23	22	14.0	4390	3810
23	16	8.0	2310	...
23	14	6.0	1490	...

Results of Load Tests:

The first load test was begun 3 hr after driving was completed; the second load test was begun 21 hr after driving was completed, and subsequent tests were run on the same pile at times suggested by the results obtained: approximately 3, 7, 14, 23, and 33 days after driving was completed.

The pile was loaded in increments of 500 to 1000 lb for the first few loads, and the increments were decreased as the ultimate supporting capacity of the pile was approached. Readings of the pressure gages were made usually after applying every second load increment. In each test a load *versus* settlement curve was plotted as the test progressed, and loading was stopped when settlement increased greatly with little increase in load.

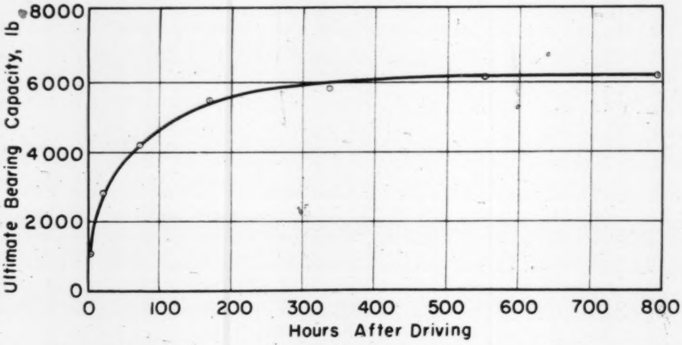

FIG. 12.—Increase in Ultimate Bearing Capacity with Time.

The results of these tests are summarized in Fig. 12. It was anticipated that there would be an increase in bearing capacity of the pile with time, but the magnitude of the increase was surprising. The ultimate load of 6200 lb for the final test was 5.4 times as great as the ultimate load of 1150 lb measured in the initial test. About 88 per cent of the increase in bearing capacity occurred in 8 days; the remaining 12 per cent increase occurred during the next 25 days.

Results of Pressure Measurements:

Pressures During Driving.—During the driving operation, pressure gages were read after each 2 ft of pile penetration; several minutes were required to take all of the readings. Data indicate that the pressures built up rapidly as the pile was driven and then dropped off rapidly when driving was stopped; therefore, it is likely that the gage readings indicate pressures less than the maximum. The pressures which were recorded during and immediately after driving are shown in Table I.

Residual Pressures.—At the conclusion of the test period, care was taken to get an accurate determination of the

TABLE II.—RESIDUAL PRESSURES.

PORE-WATER PRESSURES

Gage	Depth, ft	Measured Pressure, lb per sq ft	Computed Hydrostatic Pressure, lb per sq ft
No. W-1......	22.0	1105	1102
No. W-2......	20.0	1090	976
No. W-3......	18.0	825	850
No. W-5......	14.0	560	598
No. W-6......	12.0	445	472
No. W-7......	10.0	335	346

TOTAL PRESSURES

Gage	Depth, ft	Measured Pressure, lb per sq ft	Measured Pressure Minus Pore-Water Pressure, lb per sq ft	Gross Estimated Effective Overburden Pressure, lb per sq ft	Gross Effective Pressure Ratio
No. T-1.....	22.0	1295	193	1354	0.14
No. T-2.....	20.0	1295	319	1256	0.25
No. T-3.....	18.0	1480	630	1158	0.54
No. T-4.....	16.0	1020	296	1060	0.28
No. T-5....	14.0	830	232	962	0.24

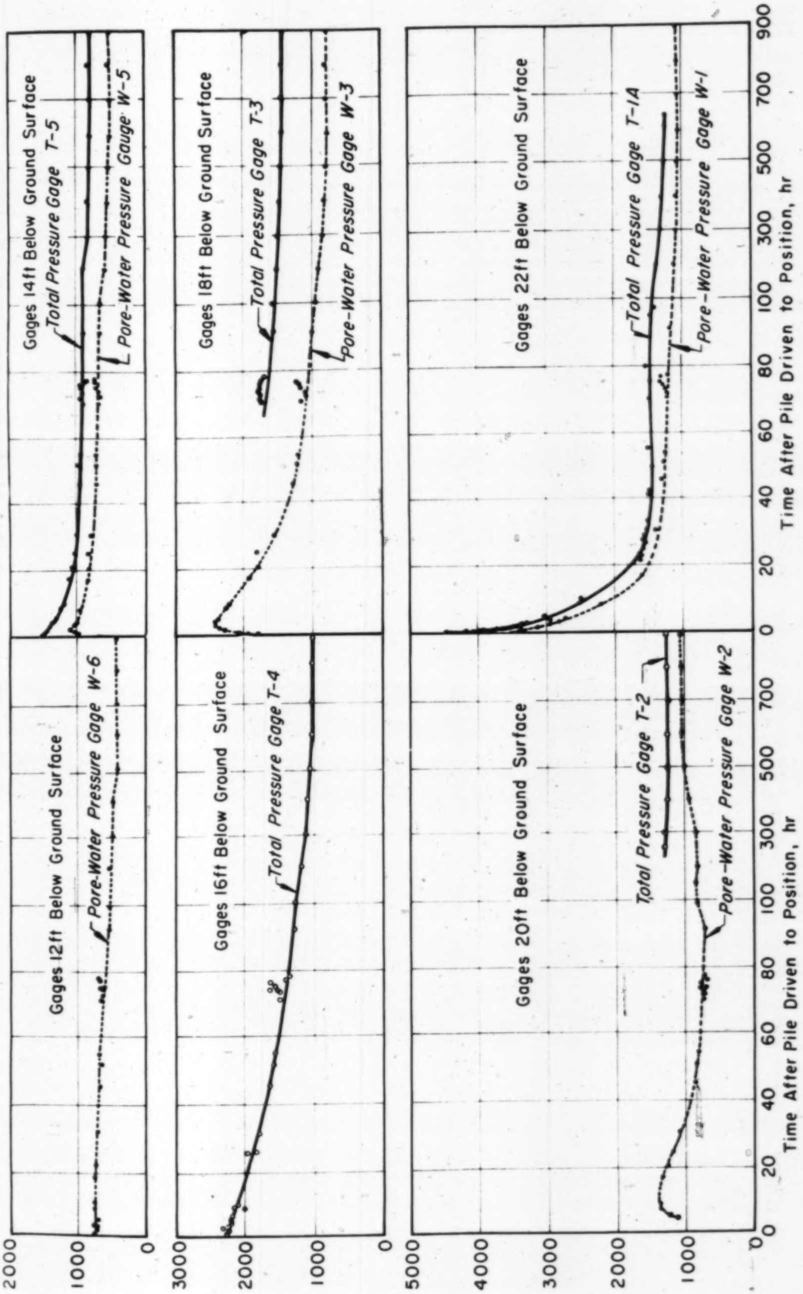

FIG. 13.—Pressure Measurements at Pile Wall.

residual total pressures and pore-water pressures. These pressures are shown in Table II. It will be noted that there is excellent agreement between the final readings of the pore-water pressure gages and the computed hydrostatic pressures.

Decrease in Pressures with Time.—Troubles developed in some gages during driving and in others after driving was completed. Sometimes it was possible to arrange new circuits so that the defective gages could be put back into use. Pressure gage readings were taken on all usable gages throughout the test period; readings were taken very frequently during the early part of the test and some of the pressure decay curves are well defined.

Pressures which were recorded are shown in Fig. 13, with the same datum being used for plotting total pressures and pore-water pressures for both gages at a particular level.

Most of the pore-water pressure gages showed a pressure increase during the first few hours. This can probably be attributed to the movement of water from the soil which is required to actuate the gages; the permeability of the clay was low, and some time would be required before equilibrium was obtained between the pressure of the gage water and that of the pore water in the soil. The data from gage No. W-1, which was nearest the pile point, probably best represents the true form of the pore-water pressure decay curve.

The total pressure gages indicated a rapid decrease in pressure during the first part of the test and reached an equilibrium relatively soon. Gage No. T-1A shows data taken on pile No. 3, because gage No. T-1 on pile No. 4 became inoperative.

Effective soil pressure normal to the pile wall could be determined by subtracting pore-water pressure from total pressure. Since the shear strength of clay increases with an increase in effective pressure, it can be reasoned that the effective soil pressure normal to the pile wall should increase with time after driving. There was an increase in bearing capacity of the pile and an increase in soil shear strength. However, the pressure measurements show no consistent increase in effective pressure. Examination of the results for gages Nos. T-1A and W-1, for example, shows two cycles of increase and decrease in the effective pressure, and not a consistent increase as might be expected.

That there was an increase in the bearing capacity of the pile with no apparent increase in effective pressure is difficult to believe. It is possible that the total pressure measurements are erroneous, but none of the three pairs of gages that can be examined shows an increase in effective pressure with time. The excellent agreement between the measured values of the residual pore-water pressures and the hydrostatic pressures gives confidence in the measurements obtained from the pore-water pressure gages.

Pressure Effects Due to Driving Adjacent Piles.—On two occasions it was possible to observe pressure gages which were affected by driving a pile nearby. In both instances the pressure gages were at equilibrium prior to driving the neighboring pile. In several respects, conditions were favorable for this type of measurement, namely:

1. The pressure measuring gages received no sharp shocks such as those which occurred when the gages were on a driven pile.
2. Temperature changes, which might cause a zero shift, were slight at most.
3. Previous readings indicated whether or not zero shift was occurring due to reasons other than temperature changes.

Even under the favorable conditions

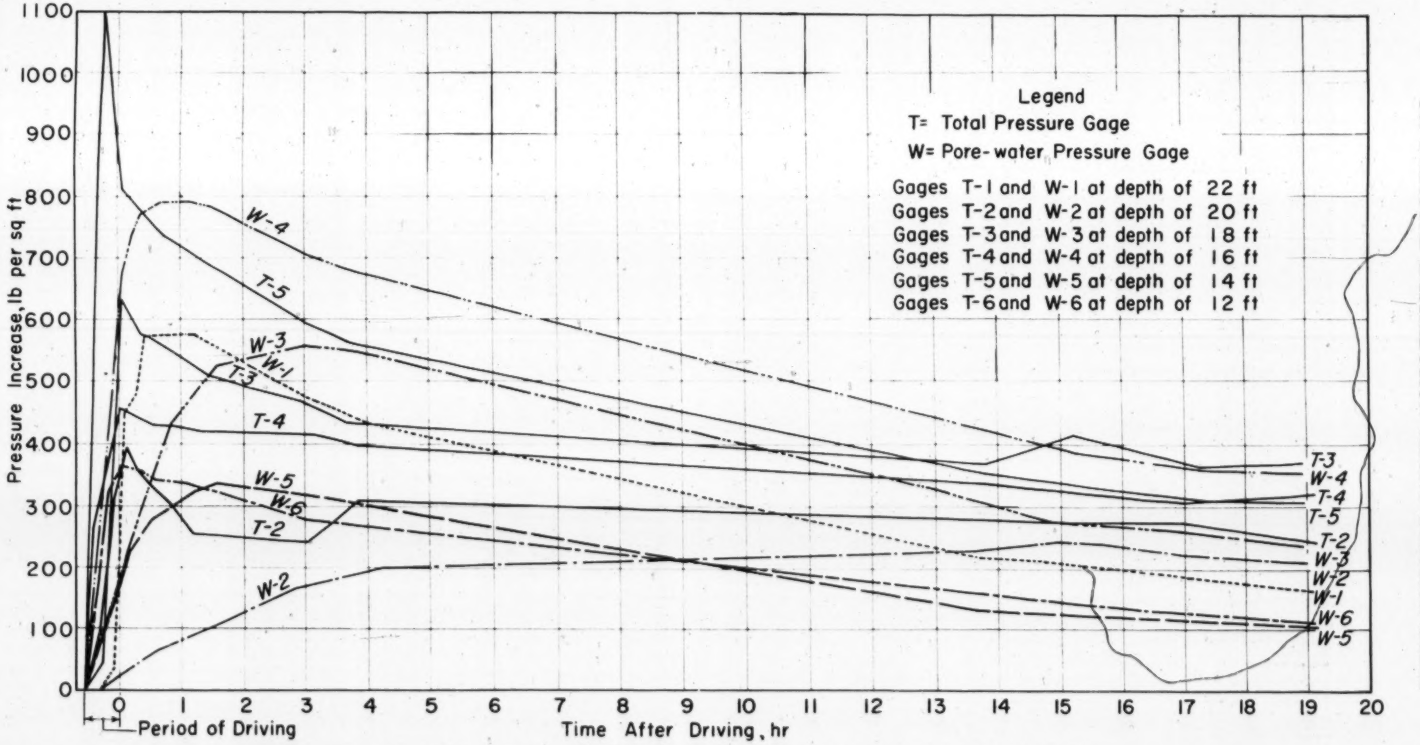

FIG. 14.—Response of Gages on Pile No. 4 to Driving Neighboring Pile 3.75 ft Away.

described, the pressure measurements are not precise because a deflection of the gage diaphragm was required for pressure to register. The inward deflection of the diaphragm of a total pressure gage (about 0.0004 in. for 100 lb per sq ft) could cause arching in the soil and a reduction in pressure on the diaphragm. The water squeezed from the soil for the deflection of the diaphragm of a pore-water gage (about 0.012 ml for 100 lb per sq ft) could have some effect on the pore-water pressure in the vicinity of the gage. These limitations must be considered in evaluating the quantitative analyses which are made later.

The first opportunity for observing pressure effects on a pile due to driving a neighboring pile came during the preliminary work. Pile No. 1, a piece of 4-in. pipe containing experimental gages, was in place and the gages were at equilibrium. Pile No. 2, a 6-in. pipe, was driven 7.4 ft away. Figure 15 shows the effect on a pore-water pressure gage located on pile No. 1. There was a slow increase in pressure of about 90 lb per sq ft over a period of 30 hr, followed by a gradual reduction in pressure over a period of several days. The total pressure gages on pile No. 1 were inoperative at that time.

Near the end of the test, pile No. 5 was driven 3.75 ft away from instrumented pile No. 4. Pressure effects on pile No. 4 (Fig. 14) were noted as soon as driving began; the hammer blows on pile No. 5 could be detected by the sudden sweep of the needle on the strain indicator. Figure 14 shows that the pressures were changing rapidly and the maximum pressures probably were not recorded.

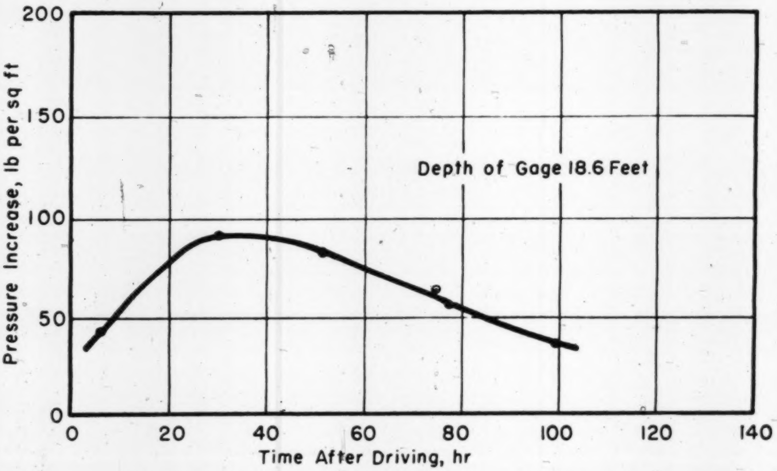

FIG. 15.—Response of Pore-Water Pressure Gage on Pile to Driving Neighboring Pile 7.4 ft Away.

As in the case of pile No. 1, the pore-water pressure gages on pile No. 4 showed a short period of pressure increase followed by a rather slow decrease. These phenomena are in general agreement with the diffusion theory. For the determination of pore-water pressure changes at some distance from a driven pile, the diffusion equation for the application of an instantaneous cylindrical surface source in an infinite solid leads to a somewhat simpler solution than that previously described. If observations are made several diameters away from a driven pile, the solution should be approximately correct. The theory is given in the Appendix, and it is shown that the theoretical change in pore-water pressure with time at points some distance from a driven pile is similar in form to the curves in Figs. 14 and 15 showing the response of the pore-water pressure gages to pile driving. Furthermore, in each case the rate and magnitude of the response can be analyzed and used to predict, with a fair degree of accuracy, the rate of decay of pore-water pressure at the wall of the driven pile.

Figure 14 shows some erratic results when measurements from certain gages are compared. For example, the pore-water pressures measured by gage No. W-4 are larger than the total pressures measured by gage No. T-4, while the reverse is true for gages Nos. W-5 and T-5. The lack of uniformity in the results may be due partially to the erratic distribution of shells in the soil. Some of the soil tested contained 17 per cent shells, based on dry weights of solids excluding shells, with some shells more than an inch wide. Other samples contained no shells. The occurrence of shells with depth was not predictable, so the data on Fig. 10 do not yield to an analysis based on whether or not the shells existed at a particular depth.

It appears possible, however, to analyze the results shown in Fig. 14 by averaging values obtained from all of the pore-water pressure gages and then by averaging values obtained from all of the total pressure gages. The variation of the average values of the increase in total pressure and pore-water pressure with time is shown in Fig. 16. It may be seen that, during the first 7 hr after pile driving, the measured increase in total pressure was essentially equal to the measured increase in pore-water pressure alone. However, from that time until the end of the test, part of the increase in total pressure appears to be due to an increase in effective pressure.

The data indicate that the driving of a pile will affect soil to a distance of several diameters away. The increase in effective pressure, which was indicated, might be expected to increase the soil shear strength; however, no direct determination of any such effect was made.

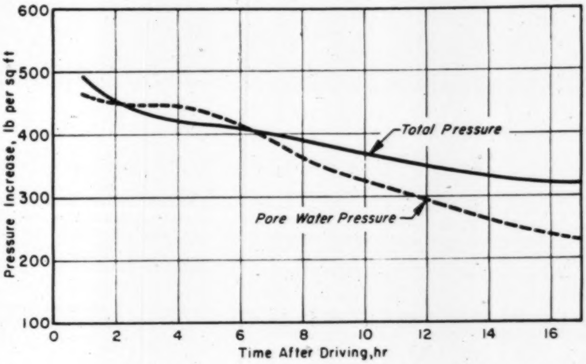

FIG. 16.—Average Response of Gages on Pile No. 4 to Driving Neighboring Pile 3.75 ft Away.

RELATIONSHIP BETWEEN SHEAR STRENGTH, PORE-WATER PRESSURE, AND BEARING CAPACITY OF PILE

A comparison between the rates of increase in shear strength of the soil and bearing capacity of the pile and the rate of decrease in excess hydrostatic pressure in the pore water is shown in Fig. 17. It will be seen that there is excellent agreement between the rate of increase in shear strength of the soil and the rate of decrease in excess hydrostatic pressure. The rate of increase in bearing capacity of the pile lags behind somewhat, but this is probably due to a time lag in the development of bond between the soil and the pile. The general agreement in these results would seem to indicate that a means of determining the rate of dissipation of pore-water pressure might provide a satisfactory indication of the time required for a pile to develop its maximum supporting capacity.

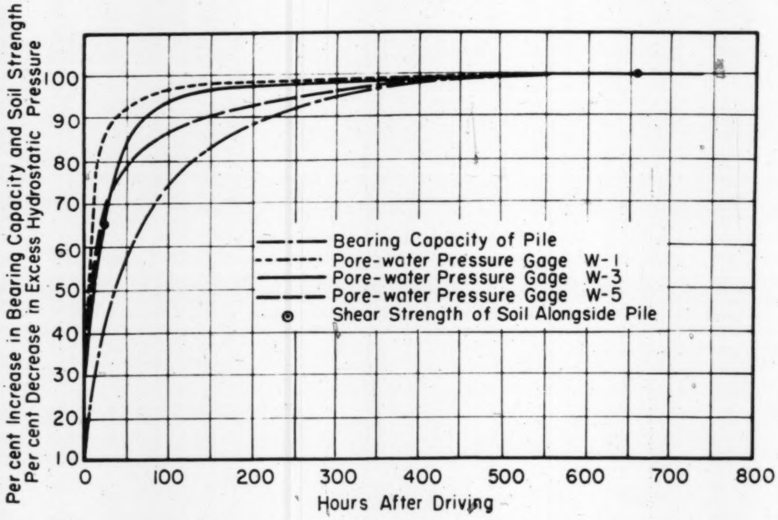

FIG. 17.—Comparison of Rate of Change of Bearing Capacity, Soil Strength and Excess Hydrostatic Pressure.

COMPARISON OF THEORIES WITH MEASURED PRESSURES

Pressures During Driving:

In order to compute the total pressures that might develop during the driving of a pile into clay by the theory previously described, it is necessary to determine values for τ_i and τ_o, the shearing resistances along the inner and outer faces of the cylinder of viscous fluid, and the value of *b*, expressing the outer radius of the cylinder. The value of τ_i was considered to be equal to the average skin friction developed between the pile and soil immediately after driving was completed. This was determined by dividing the bearing capacity of the pile at time zero (700 lb, obtained by extrapolation of the bearing capacity *versus* time curve) by the embedded area of the pile (24 sq ft), which was found to be 29 lb per sq ft. The shearing resistance long the outer surface of the cylinder was considered to be equal to the shear strength of the disturbed soil adjacent to the piles, 140 lb per sq ft.

From the fact that the soil heaved only 0.8 ft into the bottom of the casing, it is evident that some of the soil displaced by the pile moved outside the casing. Thus, the value of *b* is thought to be more than 2.5, the approximate ratio between radius of casing and radius of pile. Using values for *b* of 3.5 and 4.5, pressures were computed from Eq 1; the results are tabulated in Table III.

Examination of the table shows clearly that the theory cannot explain all the pressures measured. The principal difficulty is that different pressures were measured at the same depth, depending on the distance of the measuring gage from the pile point. For example, at a depth of 14 ft the gage nearest the pile point measured 3290 lb per sq ft, while the gage 3 ft from the pile point measured 2040 lb per sq ft at that depth. It should be recalled that the pile driving was stopped at about each 2 ft to allow time for reading the pressure gages; about 3 or 4 hr were spent in driving. This time lag allowed pressures, created at a particular depth by the pile point, to be partially decayed before the next pressure gage reached that depth. For this reason, it is believed that the pressures measured by the total pressure gage 1 ft from the pile point give the best indication of the pressures that would have existed along the pile had it been driven rapidly into position.

TABLE III.—CALCULATED AND MEASURED TOTAL PRESSURES.

Depth Below Ground Surface, ft	Distance from Point of Pile, ft	Calculated Total Pressures, lb per sq ft		Measured Total Pressures, lb per sq ft
		$b = 3.5$	$b = 4.5$	
10.4	1	1160	935	1100
12	1	1930	1560	2740
12	3	1930	1560	1870
14	1	2900	2340	3290
14	3	2900	2340	2040
14	9	2900	2340	1490
16	1	3870	3120	3290
16	7	3870	3120	2310
17	3	4350	3510	2900
18	1	4930	3900	3790
20	1	5800	4680	4180
22	1	6760	5450	4390

Over-all agreement between calculated and measured pressures seems best for the value $b = 4.5$, and pressures calculated with that value are used for further comparison.

Theoretical values for effective pressure were computed by the method previously described using the consolidation test data for undisturbed and remolded soil shown in Fig. 6. The theoretical pore-water pressures were then obtained by subtracting the theoretical effective pressures from the computed values for total pressure.

A comparison of the theoretical and measured values of total pressure, effective pressure, and pore-water pressure is shown in Table IV. The measured pore-water pressures were obtained where possible from gage No. W-1, nearest the pile point, and the values listed are the maximum pore-water pressures immediately after driving at the various depths. The measured effective pressures were obtained by subtracting the measured pore-water pressures from the total pressures.

TABLE IV.—COMPARISON OF THEORETICAL AND MEASURED PRESSURES.

Depth Below Ground Surface, ft	Theoretical Pressures			Measured Pressures		
	Total Pressure, lb per sq ft	Effective Pressure, lb per sq ft	Pore-Water Pressure, lb per sq ft	Total Pressure, lb per sq ft	Effective Pressure, lb per sq ft	Pore-Water Pressure, lb per sq ft
12	1560	460	1100	2740	1370	1370
14	2340	520	1820	3290	1430	1620
16	3120	580	2540	3290	940	2580
18	3900	650	3250	3790	950	3150
20	4680	710	3970	4180	850	3560
22	5450	770	4680	4390	570	3820

It will be seen from Table IV that the agreement between the theoretical and measured total pressures is only fair, but the agreement between the theoretical and measured pore-water pressures is quite good. It would appear from these results that the theories previously advanced provide a reasonably satisfactory means for determining the order of magnitude of the pressures acting on a pile during and immediately after pile driving.

Residual Pressures:

After a friction pile has been in place for some time, the excess hydrostatic pressures which were set up around the pile during driving should be dissipated and the pore-water pressure at any point along the pile will be reduced to the original hydrostatic pressure. Table II shows that there is good agreement between the measured pore-water pressures at the end of the test and the hydrostatic pressures. (The water table at the end of the test was 4.5 ft below ground surface, and the unit weight of the water was assumed to be 63 lb per cu ft.)

The lateral earth pressure around a driven pile will also decrease to some limiting value, but this value is difficult to define because of the unknown stresses existing in the soil around the pile. It would be expected, however, that the ultimate value of the lateral earth pressure would be no less than the earth pressure at rest, which in cohesive soils is likely to equal approximately 90 per cent of the vertical pressure (8).

Pressure ratios can be computed from the pressure gage data, provided the effective overburden pressures can be obtained. For a consolidated soil, the effective overburden pressure can normally be obtained by the simple process of determining the effective weight of the soil overlying an area of 1 sq ft at the point in question. It is believed that such a procedure is not applicable in this case because of the effect of the consolidation of the remolded soil on the stress distribution around the pile. The consolidation of this soil is accompanied by volume change and settlement of the soil. The pile tends to resist this settlement, with a resulting imposition of load on the pile and a reduction in the effective overburden pressures on the soil near the pile wall.

Three sets of data support the hypothesis that the effective overburden pressure in the vicinity of the pile is reduced by load transfer to the pile.

First, following a loading test many of the load-measuring gages on the pile returned to a zero reading, which was slightly lower than the zero reading at the beginning of the test, thus indicating that some load had been removed from the pile due to the performance of the loading test. It would be expected that the performance of loading tests would cause considerable reduction in the magnitude of the load which was transferred to the pile by the settling soil; however, some load would be imposed on the pile. The loading test period is extremely short compared to the time required for much consolidation, and load transfer could redevelop between tests.

TABLE V.—MAGNITUDE OF LOAD IMPOSED ON PILE BY OVERBURDEN.

Gage	Depth Below Ground Surface, ft	Depth of Penetration into Soil, ft	Load, lb
No. 2	21.3	13.3	2000
No. 3	20.7	12.7	180
No. 4	19.3	11.3	1880
No. 5	18.7	10.7	1120
No. 6	17.3	9.3	220
No. 7	16.7	8.7	180
No. 8	15.3	7.3	400
No. 9	14.7	6.7	450
No. 10	13.3	5.3	0

Secondly, the zero readings of the load-measuring gages on the pile changed gradually as the test period progressed. These changes were due either to zero drift of the gages or to imposition of load on the pile during the 4 weeks of the test period. The loads in the pile, as indicated by the changes in zero readings of the load gages at the end of the test, are shown in Table V. There was undoubtedly some zero drift as indicated by the lack of uniformity in the data shown in

Table V, but nevertheless a definite trend of load application is indicated. The load of 2000 lb on the pile at gage No. 2, at a depth of penetration into soil of about 13 ft, indicates that the pile is supporting about 40 cu ft of soil above that point, amounting to all the soil within about 9 in. from the pile wall. This result must be considered very approximate until more data are obtained.

Thirdly, the hydrostatic pressure ratios based on the gross estimated effective overburden pressure, as shown in Table II, are very much lower than expected. The magnitude of reduction in the overburden pressure near the pile wall, due to the transfer of some of the weight of the overburden to the pile, is impossible to compute from the data obtained; therefore, the actual hydrostatic pressure ratios cannot be reported.

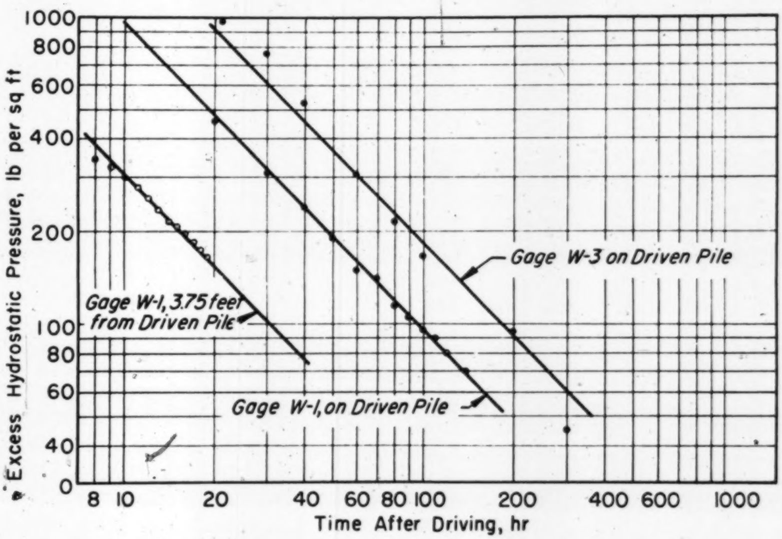

Fig. 18.—Logarithmic Plot of Excess Hydrostatic Pressure *versus* Time.

Comparison of Theory with Measured Excess Hydrostatic Pressure Decay:

The equation derived for the eventual decay of excess hydrostatic pressure in the soil around a pile, Eq 5, which applies for large values of time, can be compared to excess hydrostatic pressure measurements at the pile wall and also to measurements some distance away from a driven pile.

The best method for comparing experiment and theory is to plot the experimental results on logarithmic graph paper. Equation 5, expressed in logarithmic form, becomes:

$$\log u = \log \frac{Q}{4\pi K} - \log t$$

This equation will plot as a straight line on logarithmic paper, with a slope of -1. The value of $\frac{Q}{4\pi K}$ can be obtained by reading the value of u when $t = 1$.

Figure 18 shows such plots for three sets of the data taken at times greater than 8 hr after driving; two sets were obtained from pore-water pressure gages Nos. W-1 and W-3 on the driven pile (taken from Fig. 13), and one set was recorded on pore-water pressure gage No. W-1 after driving an adjacent pile 3.75 ft away (taken from Fig. 15). There is fairly good agreement between the shape of the theoretical and experimental curves, as shown by the agreement between the plotted points and the lines that were drawn with the slope of −1. However, as might have been expected, there is considerable disagreement regarding the quantity Q/K, as determined from the various sets of data. Values of Q/K obtained from all available sets of data are tabulated in Table VI.

TABLE VI.—EXPERIMENTAL VALUES OF $\frac{Q}{K}$.

Gage	Location	$\frac{Q}{K}$, lb-sec per sq ft
No. W-1	On driven pile	4.3×10^8
No. W-3	On driven pile	8.2×10^8
No. W-1	3.75 ft away from driven pile	1.4×10^8
No. W-3	3.75 ft away from driven pile	2.0×10^8
No. W-4	3.75 ft away from driven pile	2.6×10^8
. . . .	7.4 ft away from driven pile (depth equal to that of gage No. W-1)	2.0×10^8

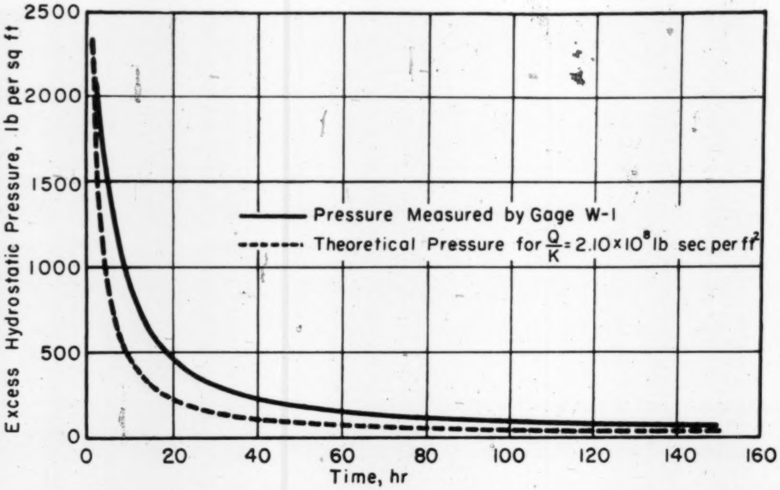

FIG. 19.—Comparison of Measured Excess Hydrostatic Pressure at Pile Wall with Theoretica Pressure.

It will be seen that the value of Q/K is larger for those measurements made on a driven pile than for those made when piles were driven in the vicinity of pore-water pressure gages. The table also shows that the value of Q/K decreases with increasing depth. The action of pile driving does not necessarily impose a constant value of Q with depth, but the value of Q/K might be expected to be constant at a given depth for points in the same general area. The disagreement between experimental values obtained for the same depth could be due to nonhomogeneity of the soil, to experimental errors in the gage readings, or simply to lack of agreement between the theory and the pressure decay phenomenon. The excellent agreement between the observed and computed values of the residual hydrostatic pressures gives confidence in the gage readings for large values of time, but unfortunately there are no other data at hand to reveal which of the other possibilities is the most likely cause of the disagreement.

The changes in pore-water pressure

recorded at some distance from a driven pile can be used to predict the rate of decay of excess hydrostatic pressure around the driven pile. For example, it may be seen from Table VI that the average value of Q/K determined from the analysis of data taken at 3.75 ft from a driven pile is 2.1 × 10^8 lb-sec per sq ft. The rate of pressure decay at times larger than about 10 hr, corresponding to this value of Q/K, can readily be determined on the logarithmic plot in Fig. 18 and then redrawn as shown in Fig. 19, where it is compared with the rate of pressure decay as measured by gage No. W-1 on the driven pile. It will be seen that the observed and predicted curves are in reasonably good agreement, indicating that the theory may be of some use in describing the pressure decay phenomena.

From a practical standpoint it is helpful to know when the decay of excess hydrostatic pressure has been accomplished, since the excess hydrostatic pressure affects soil properties and the bearing capacity of a pile.

CONCLUSIONS

The main conclusions resulting from the investigation are summarized below. The conclusions listed apply specifically to the investigation described in this paper, that is, to the study of a small-sized displacement-type friction pile which was driven into a saturated clay of low sensitivity. However, in many ways the driving and testing procedures are identical with practice, and it is believed that most of the conclusions will apply to other displacement-type friction piles driven into saturated clay.

1. The rate of increase in bearing capacity of the pile and in shear strength of the soil adjacent to the pile were in good agreement with the rate of decrease in excess hydrostatic pressure in the soil adjacent to the pile wall.

2. The initial effective pressures in the soil around the driven pile were in good agreement with values determined from the results of consolidation tests on partially remolded soil. The data indicate that pressures applied to the soil as a result of displacement caused by pile driving go principally into the pore water.

3. The rate of decay of the excess hydrostatic pressure in the soil adjacent to the wall of the displacement-type friction pile used in this investigation can be approximated by using the diffusion equation. The prediction of the rate of decay of excess hydrostatic pressure may have useful applications in practice since it enables an estimate to be made of the time required for a pile to develop its maximum supporting capacity.

4. The driving of 6-in. diameter friction piles into soft silty clay created pressures in the soil which could be detected as far away as 15 diameters and caused a pronounced effect at a distance of 7.5 diameters from the pile.

5. The values for the effective lateral pressures acting on the wall of the pile at the end of the test period, as determined from the pressure measurements, were much lower than the gross effective overburden pressures in the soil; there were indications that the effective vertical pressures in the soil adjacent to the pile were reduced because of the resistance of the pile to the settlement of the disturbed soil.

Acknowledgment:

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APPENDIX

PORE-WATER PRESSURES DEVELOPED SOME DISTANCE AWAY FROM A DRIVEN PILE

The solution for the heat diffusion equation for the case of an instantaneous cylindrical surface source applied in an infinite mass, allowing diffusion inward and outward from the source, has been given by Carslaw and Jaeger (**6**, p. 216):

$$u = \frac{Q}{4\pi Kt} e^{-(r^2+c^2)/4Kt} I_0\left(\frac{rc}{2Kt}\right) \ldots \text{A-1}$$

where:
u = temperature,
t = time,
K = diffusivity constant,
r = radial coordinate,
c = radius of the instantaneous source,
Q = strength of instantaneous source, and
I_0 = Bessel function of imaginary argument of order zero.

The above equation should be an approximate solution for the diffusion around a driven pile if the distance r to the observation point is large compared to the pile diameter. That inward diffusion is allowed, when actually it cannot occur across the wall of the driven pile, is thought to make little difference in the results which are obtained at points relatively far away from the driven pile. The use of this solution has the advantage that it can be applied at all values of time. The simplified solution presented earlier is only applicable for large values of time.

For the case of the pile the symbols above are redefined as follows:
u = pressure in lb per sq ft,
Q = strength of instantaneous surface source in lb,
t = time,
K = constant, sq ft per sec,
r = distance from driven pile to point of observation in ft, and
c = radius of source (assumed same as pile radius) in ft.

It is interesting to compare results from this equation with those obtained previously from the simplified equation for the case of large values of time. For the observation made 7.4 ft away from a pile (with c = 0.25 ft), Eq A-1 becomes:

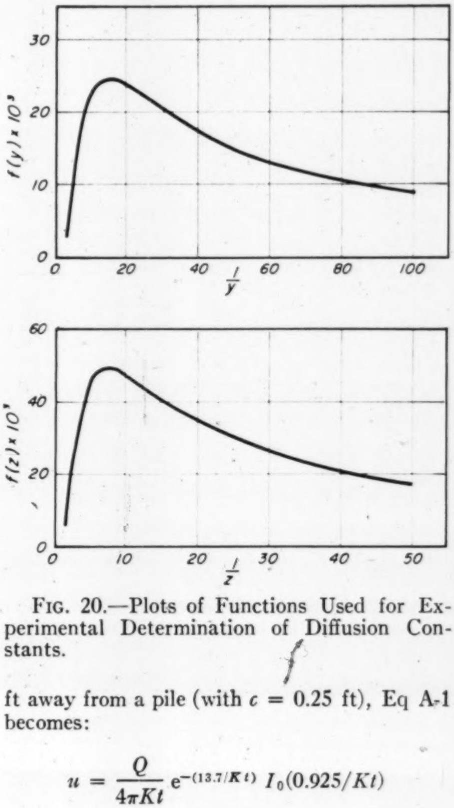

FIG. 20.—Plots of Functions Used for Experimental Determination of Diffusion Constants.

$$u = \frac{Q}{4\pi Kt} e^{-(13.7/Kt)} I_0(0.925/Kt)$$

For convenience in calculating, substitute

$$y = \frac{0.925}{Kt}$$

Then

$$u = \frac{Q}{11.62} ye^{-(14.8y)} \times I_0(y) = \frac{Q}{11.62} f(y) \quad \ldots \text{A-2}$$

The terms involving y, called $f(y)$, in Eq A-2 are plotted *versus* $1/y$ in Fig. 20. It may be seen that the function plots into a curve which is similar in shape to the curves showing the response of the pore-water pressure gages to pile driving.

The problem now is to fit the theoretical curve in Fig. 20 to the experimental curve in Fig. 14. This can be done by comparing the maximum ordinates of the two curves and by comparing the distance along the abscissas between the values of one half the maximum ordinates.

In this manner the following values can be obtained:

	Fig. 14	Fig. 20
Difference between half values of maximum ordinate........	81 hr or 291,600 sec	57.5 units of $1/y$
Maximum ordinate...........	91 lb per sq ft	0.025 units of $f(y)$

These values can then be used to compute K and Q as follows:

$$1/y = Kt/0.925$$

$$\therefore K = \frac{(57.5)(0.925)}{291{,}600} = 0.000183 \text{ sq ft per sec}$$

$$u = \frac{Q}{11.62} f(y)$$

$$\therefore Q = \frac{(11.62)(91)}{0.025} = 42{,}300 \text{ lb}$$

Then

$$Q/K = 2.3 \times 10^8 \text{ lb-sec per sq ft}$$

This value is in good agreement with the value of 2.0×10^8 lb-sec per sq ft, which was obtained by use of the simplified equation for large values of t.

For the observation made 3.75 ft away from a driven pile, Eq A-1 becomes:

$$u = \frac{Q}{5.89} ze^{-(7.53z)} I_0(z) \quad \ldots\ldots\ldots \text{A-3}$$

where:

$z = 0.469/Kt.$

The terms involving z are plotted *versus* $1/z$ in Fig. 20. In Fig. 20 the difference between the half values, called t_2, is 29.8 divisions of $1/z$, and the maximum ordinate is 0.049 divisions of $f(z)$.

Using these values:

$$K = \frac{(1/z)(0.469)}{t_2} = \frac{13.98}{t_2}$$

$$Q = \frac{(5.89)(v_{\max})}{f(z)} = 12.01\, v_{\max}$$

Taking the appropriate values of maximum ordinate and distance between the half values from Fig. 15, the values shown in Table VII can be determined. The values of Q/K obtained from the simplified equation for the same gages were 1.4×10^8, 2.0×10^8, and 2.6×10^8. These results would seem to indicate that Eq A-1 can be used satisfactorily to describe the diffusion of excess hydrostatic pressure at points 8 diameters or more from a driven pile.

TABLE VII.

Gage	$v_{\max}$, lb per sq ft	Q, lb	t_2, sec	K, sq ft per sec	Q/K, lb-sec per sq ft
No. W-1..................	586	70,380	37260	0.000375	1.9×10^8
No. W-3..................	560	67,260	51550	0.000271	2.5×10^8
No. W-4..................	792	95,120	55840	0.000250	3.8×10^8

THE USE OF LABORATORY TESTS TO DEVELOP DESIGN CRITERIA FOR PROTECTIVE FILTERS*

By K. P. Karpoff[1]

Synopsis

Protective filters are often used for the foundation soils (called base material in this paper) of engineering structures to allow drainage and prevent erosion or uplift pressure from seepage water. It is important that the gradation of the filter materials be carefully selected with respect to the gradation of the base materials which are to be protected. The laboratory testing program reported herein was conducted to develop criteria for the selection of suitable filter gradations.

The apparatus designed for this filter testing program consisted essentially of transparent plastic cylinders, 8 in. in diameter, bolted together and connected to a water supply system. Layers with different gradations of base and filter materials were compacted in the cylinders and subjected to hydraulic heads ranging from 2 to 30 ft. The series of filtration tests provided data for a comparison of the functioning of various combinations of base and filter materials through observations and photographs, measurements of the unit flow of water through assemblies, and determination of any quantitative changes in base and filter materials which occurred during the tests. This study led to the recommendation of simple numerical relationships by which a suitable gradation of filter material could be selected to protect given base materials.

Engineers generally agree that drainage is one of the most important items in construction in order to provide safeguards against failure of the structure due to uplift pressures, and protection of fine materials must be provided to prevent gradual or rapid erosion of the foundation. Where drainage is required, it is generally necessary to use some type of protective filter to collect the water and conduct it to a place of discharge.

A common use for a protective filter is in a subsurface drainage system where a trench is backfilled with sand and gravel surrounding a perforated or open-joint pipe. The seepage water in the natural soil or subgrade flows through the filter into a pipe in which it is carried to a place of discharge. Protective filters are also used under concrete spillways of dams and concrete canal linings, in foundation-pore water pressure relief wells at the downstream toe of earth dams or levees, and in other hydraulic structures where the relief of the excessive water pressure or lowering of the phreatic line is necessary for improving the stability of the structure.

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* Presented at the Fifty-eighth Annual Meeting of the Society, June 26–July 1, 1955.

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TABLE I.—SCHEDULE OF FILTER ASSEMBLIES FOR LABORATORY EXPERIMENTAL TESTS.

	Base Material (Noncohesive)	Filter No. 1	Filter No. 2	Filter No. 3	Filter No. 4	Filter No. 5	Filter No. 6
				UNIFORM GRAIN-SIZE FILTER			
Series A tests	S-curve[a] 5% clay (5μ)[b] No. 50 max Silt	Straight[a] No. 100 min[b] No. 50 max $R' = 4.0$[c]	Straight[a] No. 50 min[b] No. 40 max $R' = 7.1$[c]	Straight[a] No. 40 min[b] No. 30 max $R' = 9.9$[c]	Straight[a] No. 30 min[b] No. 16 max $R' = 15.8$[c]	Straight[a] No. 16 min[b] No. 8 max $R' = 31.9$[c]	
Series B tests	Straight[a] No. 200 min[b] No. 100 max Fine sand	Straight[a] No. 40 min[b] No. 30 max $R' = 4.9$[c]	Straight[a] No. 30 min[b] No. 16 max $R' = 7.8$[c]	Straight[a] No. 16 min[b] No. 8 max $R' = 15.7$[c]			
Series C tests	Straight[a] No. 50 min[b] No. 30 max Fine med. sand	Straight[a] No. 16 min[b] No. 8 max $R' = 3.8$[c]	Straight[a] No. 8 min[b] No. 4 max $R' = 7.7$[c]	Straight[a] No. 4 min[b] ¼″ max $R' = 12.6$[c]	Straight[a] No. 4 min[b] ⅜″ max $R' = 15.2$[c]		
Series D check test	S-curve 2% clay (5μ) ¼″ max Sandy silt	Straight[a] No. 16 min[b] No. 4 max $R' = 6.0$[c]					
				GRADED FILTERS			
Series A_1 tests	S-curve[a] 6% clay (5μ)[b] No. 50 max Silt	Concave[a] No. 200 min[b] ¼″ max $R' = 60.4$[c] $R'' = 69.2$[d]	Concave[a] No. 200 min[b] ¼″ max $R' = 45.4$[c] $R'' = 28.6$[d]	Straight[a] No. 200 min[b] ¼″ max $R' = 13.5$[c] $R'' = 11.3$[d]	Convex[a] No. 200 min[b] ¼″ max $R' = 4.5$[c] $R'' = 8.1$[d]	S-curve[a] No. 200 min[b] ¼″ max $R' = 14.7$[c] $R'' = 17.4$[d]	Convex[a] No. 200 min[b] ¼″ max $R' = 7.2$[c] $R'' = 10.5$[d]
Series B_1 tests	S-curve[a] 6% clay (5μ)[b] No. 50 max Silt	Concave[a] No. 200 min[b] ¾″ max $R' = 98.2$[c] $R'' = 45.3$[d]	Straight[a] No. 200 min[b] ¾″ max $R' = 22.8$[c] $R'' = 13.0$[d]	Convex[a] No. 200 min[b] ¾″ max $R' = 9.1$[c] $R'' = 11.6$[d]	Concave[a] No. 200 min[b] ¾″ max $R' = 48.3$[c] $R'' = 27.5$[d]		
Series C_1 check tests	S-curve[a] 5% clay (5μ)[b] ¼″ max Sandy silt	Convex[a] No. 200 min[b] 3″ max $R' = 58.0$[c] $R'' = 40.0$[d]	Convex[a] No. 8 min[b] 3″ max $R''' = 4.0$[e]				

[a] Shape of gradation curve.

[b] Minimum and maximum grain size.

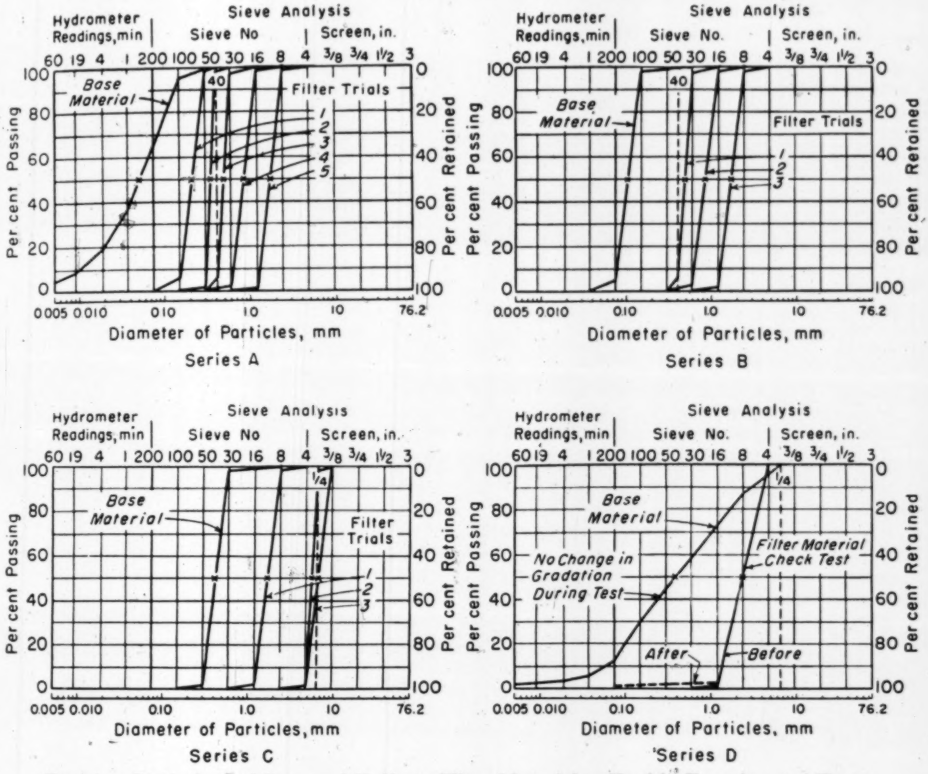
[c] $R' = \frac{50\% \text{ size of filter material}}{50\% \text{ size of base material}}$.

[d] $R'' = \frac{15\% \text{ size of filter material}}{15\% \text{ size of base material}}$.

[e] $R''' = \frac{15\% \text{ size of filter material}}{85\% \text{ size of base material}}$.

A material selected for the protective filter has to satisfy four main requirements as follows:

(*a*) The filter material should be more pervious than the base material in order that there will be no hydraulic pressure built up to disrupt the filter and adjacent structures.



Series A Series B

Series C Series D

FIG. 1.—Gradations of Base and Uniform Filter Materials—Used in Experimental Tests.

(*b*) The voids of the in-place filter material must be small enough to prevent base material particles from penetrating the filter which causes clogging and failure of the protective filter system.

(*c*) The layer of the protective filter must be sufficiently thick to provide a good distribution of all particle sizes throughout the filter and also to provide adequate insulation for the base material where frost action is involved.

(*d*) Filter material particles must be prevented from movement into the drainage pipes by sufficiently small slot openings or perforations or additional coarser filter zone may be necessary.

TESTING PROGRAM

Although considerable excellent research on this problem had been conducted by others previously,[2,3,4] the Bureau

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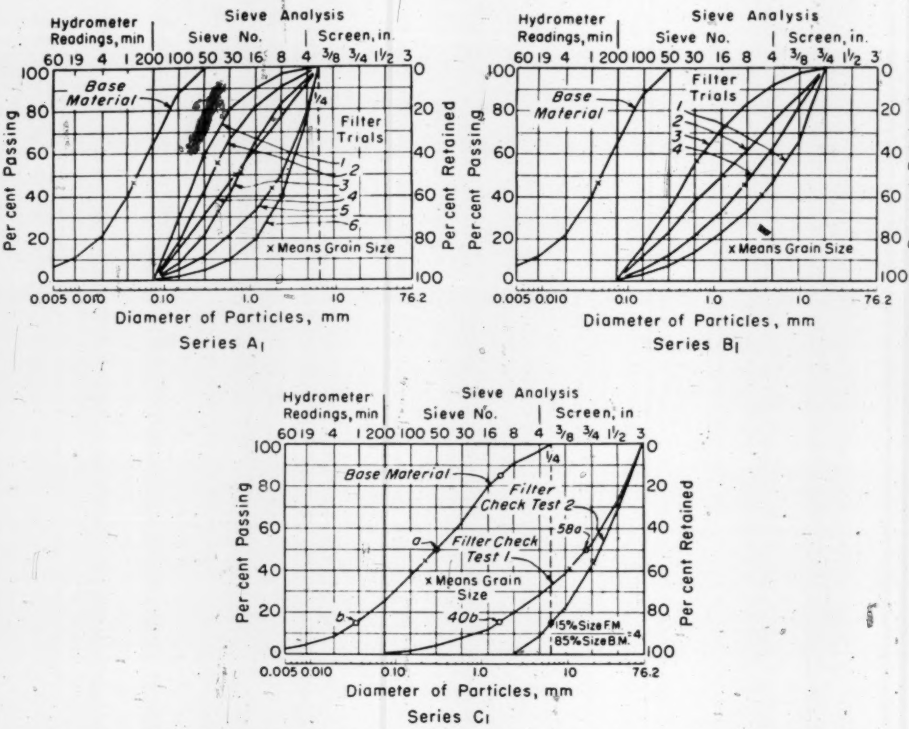
[2] G. E. Bertram, "An Experimental Investigation of Protective Filters," Graduate School of Engr. Pub. 267, Series 7, 1940.

[3] Engineering Manual, Chapter XXI, "Design of Drainage Facilities for Airfields," Office of Chief of Engineers, War Department, Part II, February, 1943.

[4] The laboratory experimental tests of the Armco Drainage Product Assn. resulted in a recommendation that perforations in the pipe should be located between 22½ deg to 30 deg down from the horizontal axis to prevent the filter material from entering into a drain pipe. (H. E. Cotton, "Highway Subdrainage and Base Drainage," Roads and Streets, June 1945, p. 94)

of Reclamation Earth Laboratory undertook extensive experimental studies to determine methods for designing protective filters which would be applicable to specific, severe field conditions. These experimental studies were performed on "natural subrounded material," and the simple numerical relationship between base and filter materials was determined for designing protective filters.



Series A_1

Series B_1

Series C_1

FIG. 2.—Gradations of Base and Graded Filter Materials—Used in Experimental Tests.

The initial laboratory program, as illustrated in Table I, was divided into the following parts:

(*a*) Determination of suitable criteria for the design of a uniform grain-size filter. A uniform grain-size filter material is defined in this paper as a material having an approximate straight-line gradation curve and a narrow range of major particle sizes with an allowable variation in approximate range of one to three particle size divisions on the USBR standard gradation sheet for sieve sizes.

(*b*) Determination of suitable criteria for the design of a graded filter. A graded filter material is defined in this paper as a material having a comparatively broad range of particle sizes. Graded material may have concave, convex, S-shaped, or straight-line gradation curves and may be defined as "poorly" and "well-graded" material, depending on their gradation curve shape.

Sand and gravel for the test filters were prepared for testing by carefully sieving into fractions retained on each sieve in a standard series ($1\frac{1}{2}$ in. to No. 200). These materials were washed, oven dried, and stored in covered cans to prevent gathering dust. From these materials the uniform grain-size filters and graded filters of different gradations were artificially prepared and the sieve analysis of base and filter materials was made. The gradation curves shown in Figs. 1 and 2 include the various gradations studied.

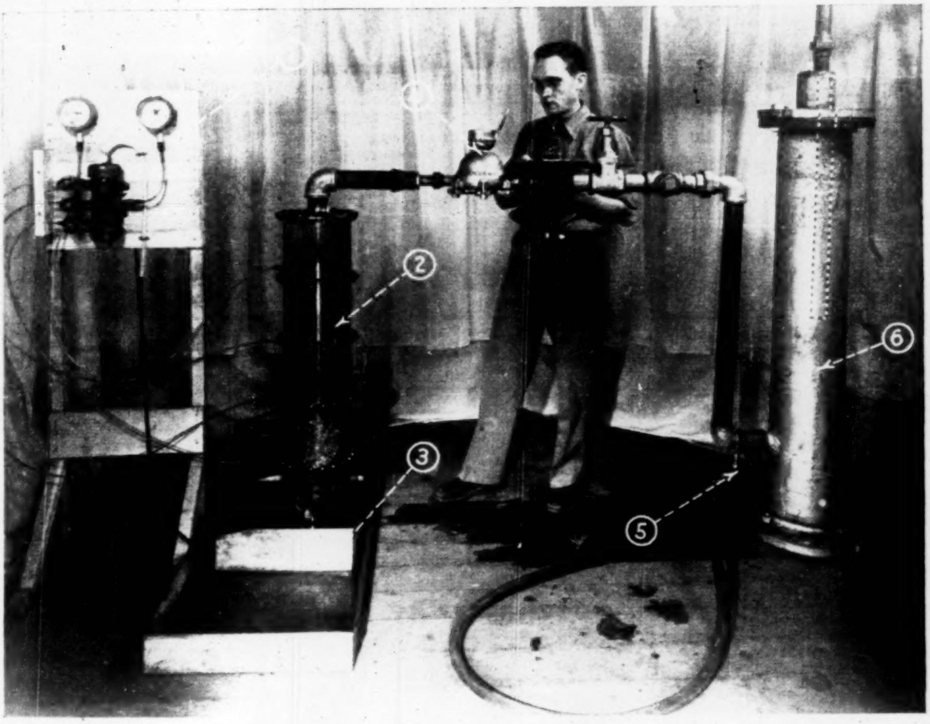


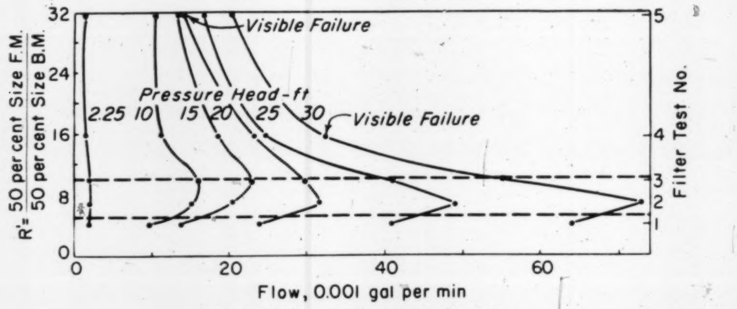
FIG. 3.—Filter Test Apparatus.
1. Instrument panel 2. Filter assembly 3. Overflow tank 4. Water meter 5. Pressure regulator 6. Equalizer tank

The physical characteristics of each material were analyzed on the basis of the degree of fineness of the soil based on mean grain size; the type of grading curve—that is, shape which indicates whether the soil has a normal statistical distribution of grain sizes or an irregular distribution; and the range of particle sizes to take in the entire gradation curve. Considering the above factors and applying them for analyses of the physical properties of the prepared filter gradations shown in Figs. 1 and 2, the following decisions were reached:

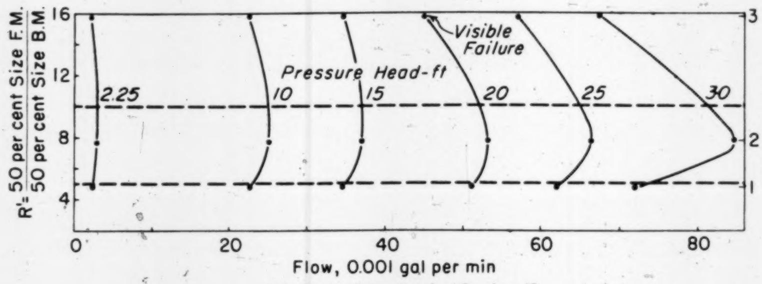
1. The physical properties of uniform grain-size material in Fig. 1 are characterized mainly by degree of fineness, as represented by the mean grain size, which is approximately represented by the 50 per cent grain size. For most base material of natural gradation the mean grain sizes fall between 40 and 60 per cent. Therefore, the relationship between the 50 per cent size of filter material to the 50 per cent size of base material was chosen as a control factor for investigation of the stability of uniform graded filters.

2. The physical properties of the graded filter materials are characterized

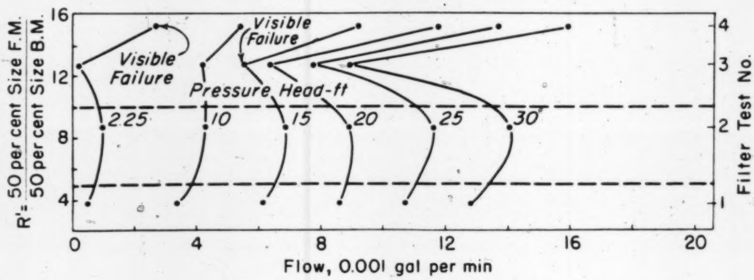
by the degree of fineness, by shape of the gradation curve, by the range of the gradation curve, and by skewness of the curve toward the fine or coarse sizes. Therefore, it was concluded that for investigation of the stability of graded filters, it is necessary to specify definite ratios between the grain sizes of filter material and the grain sizes of the base material on the basis of at least two points on their gradation curves. A study of the filter gradation curves in Fig. 3 shows that the mean grain size ranges approximately between 40 and 60 per cent. For this reason the 50 per cent grain size was selected as one point. The 15 per cent size was arbitrarily selected as the other point because it was believed that the finer portions had a high degree of importance with respect to permeability and particle movement.



(a) Test Results for Series A



(b) Test Results for Series B



(c) Test Results for Series C

FIG. 4.—Uniform Grain-Size Filter Tests.

The experimental tests of filters with uniform grain-size materials consisted of three groups, series A, B, and C, with a different type of base material for each group (Fig. 1). The experimental tests of graded filters consisted of two groups, series A_1 and B_1, of filters having an identical base material but each group of filters involved a different range in gradation curve and different maximum grain sizes (Fig. 2). For each of uniform and graded filter tests an additional test series (series D and C_1, respectively) was performed to check the experimental test results.

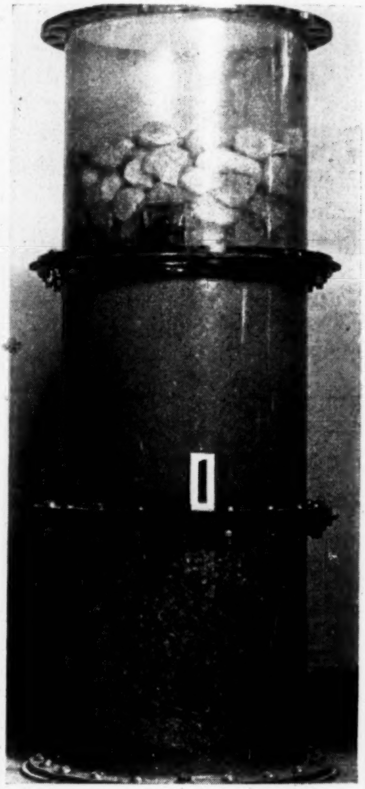


FIG. 5.—Uniform Grain Size Filter Series D-Check Tests After Completion of Filtration.

More recent tests for actual projects under construction provided data for experimental tests with crushed rock filters since such materials were proposed for use. These tests are briefly discussed in subsequent paragraphs.

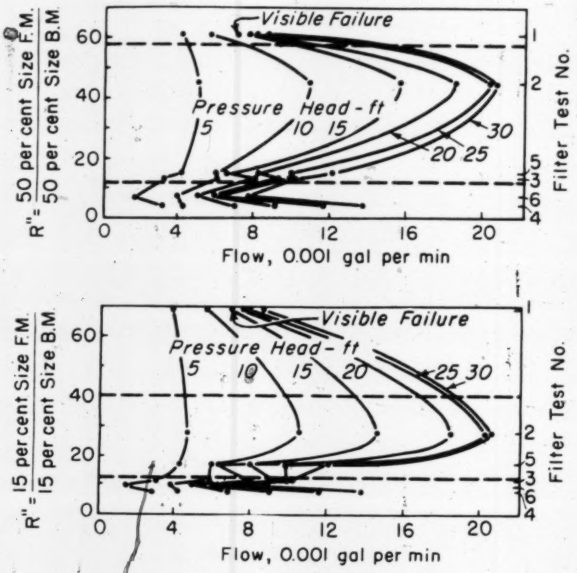
EQUIPMENT

The apparatus designed for the filter tests, shown in Fig. 3, consisted of several transparent plastic cylinders, 8 in. high by 8 in. in diameter, bolted together. Rubber gaskets $\frac{1}{16}$ in. in thickness were provided to seal the joints between the cylinders. A perforated steel plate, having a desired size opening to simulate pipe openings, was bolted to the bottom cylinder assembly. The whole system was placed on wooden blocks in an overflow tank. A $\frac{1}{4}$-in. steel plate 9.8 in. in diam with a 2-in. nipple in the center and one bleeder valve on the side was bolted to the top cylinder.

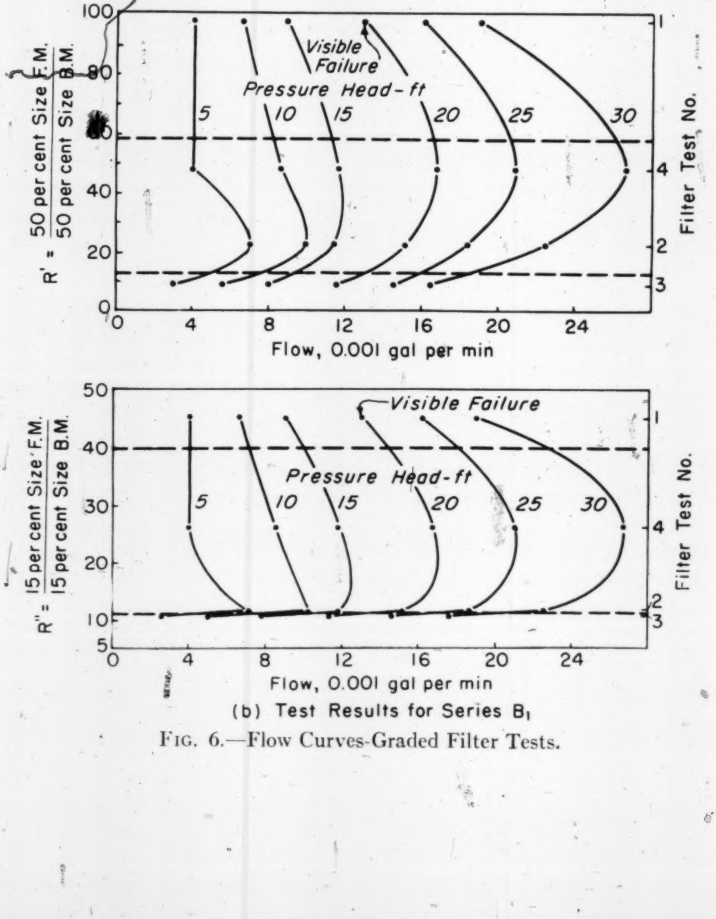
The filter assembly may be made up of any desired number of cylinders depending upon the particular condition being investigated, such as a zoned filter assembly of more than one filter layer. Layers 8 in. thick with different gradations of base and filter materials were compacted by using about one-half of the Bureau of Reclamation standard compactive effort to simulate light rolling of field installations. The laboratory compaction effort consisted of dropping a 5.5-lb hammer a distance 9 in. for 80 blows over an area of 8 in. in diameter on each 2-in. layer of soil. After placement of the soil into cylinders the filter assembly was connected to a water supply system as shown in Fig. 3 and subjected to hydraulic heads ranging from 2 to 30 ft. Hydraulic pressures at bottom of each 8-in. layer in the assembly were measured through plastic tubing to the pressure gage panel.

TEST RESULTS ON NATURAL SUBROUNDED MATERIALS

The experimental tests of filters with uniform grain-size materials as shown in Fig. 1 were divided into four series designated by letters A, B, C, and D. Series A consisted of five preliminary filtration tests in which different uniform grain-



(a) Test Results for Series A_1



(b) Test Results for Series B_1

FIG. 6.—Flow Curves-Graded Filter Tests.

size filters were used with one base material. The main filtration tests were made in the series B and C in which filter gradations, selected on the basis of experience gained in the series A tests, were used with different base materials. Series D consisted of one test made to check the design criteria established from the preceding tests. The filtration test results of series A, B, and C are expressed diagrammatically in Fig. 4. The diagrams show the relationship between the grain size ratio, R', of the filter material (FM) and the base material (BM) to be:

$$R' = \frac{50 \text{ per cent size } FM}{50 \text{ per cent size } BM}$$

to the unit flow at different hydraulic heads. The filter with 50 per cent grain-size ratios within the limits shown by the heavy dashed lines produced the best performance at different hydraulic heads permitting greatest flow without noticeable effect on the stability of the filters. For this reason the values of grain-size ratios 5 and 10 were adopted as minimum and maximum limits for the design criteria of the uniform grain-size filters. Test series D was run under similar conditions to those of the previous tests to check the criteria and the results are shown in Fig. 5. There was no visible indication of failure in this filter. There was insignificant difference in gradation curves of filter material obtained prior to and after filtration test as indicated in the gradation curves in Fig. 1, series D.

The experimental tests of filters with graded materials were divided into three series of tests designated in Fig. 2 by letters A_1, B_1, and C_1. In series A_1 six gradations of filter material were tested for determining a preliminary relationship between the grading of filters and base material. The diagram of the test results is shown in Fig. 6. The filters with ratio between the limits denoted by the heavy dash lines show the best performance regarding flow characteristics at different hydraulic heads without affecting the stability of the filters. For this reason values of grain-size ratio 12 to 58 and 12 to 40 were adopted as the limits of the 50 and 15 per cent grain-size ratios, respectively.

Test series B_1 was introduced in order to make a final decision on the limits for design criteria which were tentatively adopted after completion of the series A_1 tests. Four filter samples of graded filters having a broader range and different mean grain sizes than that in series A_1 tests were tested with the same base material as in the series A_1. The test results as shown in Fig. 6(*b*) provided additional assurance of the correctness of the selected design criteria for graded filters; that is, the limits of the criteria for the 50 and 15 per cent grain-size ratios should be 12 to 58 and 12 to 40, respectively, as shown by the dashed lines.

At the end of the experimental testing program of filters from graded materials, two check tests, series C_1, were introduced to produce the critical relationships between the base and filter materials. Gradations for this test series are shown in Fig. 2, series C_1. The gradation for one assembly was designed on the basis of the extreme coarse limit. The gradation for the other assembly was designed outside the coarse limit but within other criteria commonly used in filter design.[2] Each filter was subjected to the filtration tests at identical conditions.

After completion of these filtration tests, the following conclusions were reached:

1. The filter material which was designed on the basis of the criteria adopted in this program was stable in all respects, as shown by the photograph and the before and after gradations in Fig. 7. The stability and satisfactory performance of this filter granted additional assurance of the validity of the design criteria adopted for graded protective filters.

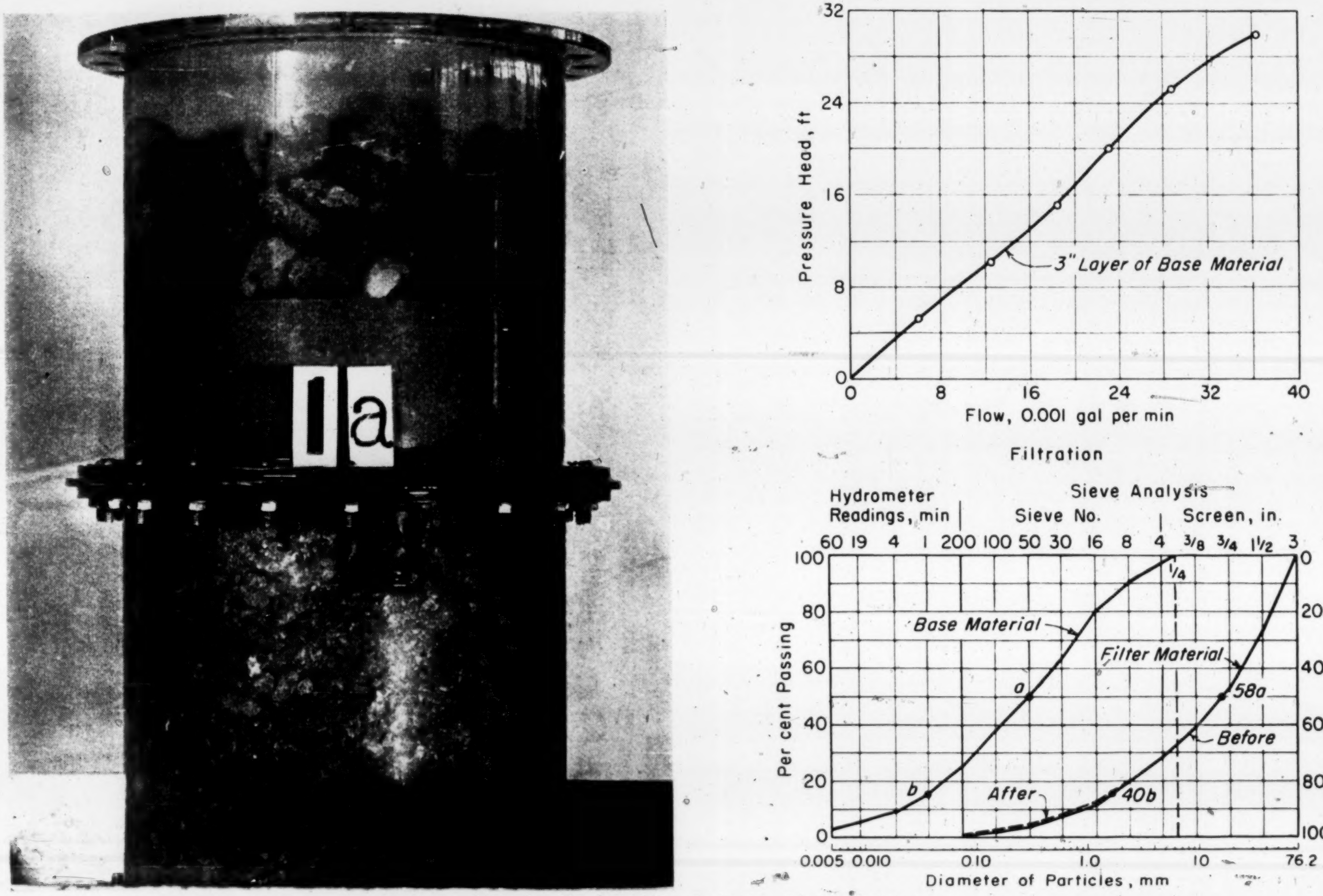
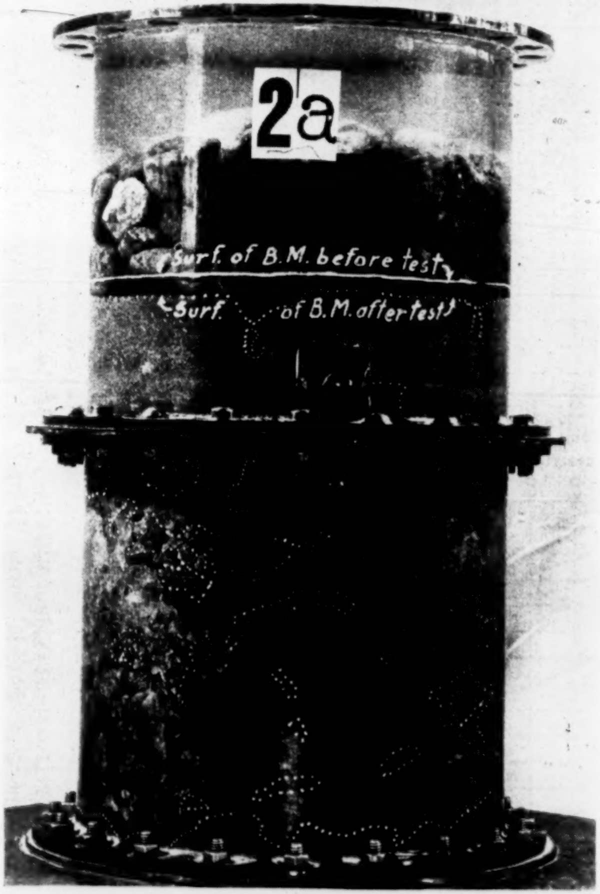
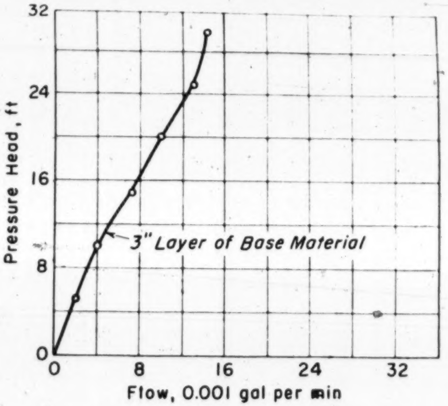
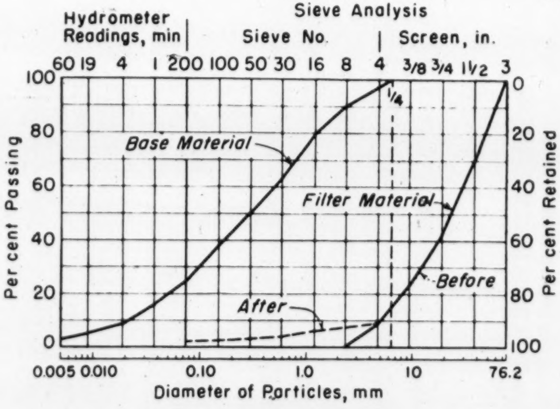


FIG. 7.—Graded Filter Series C_1, Check Test 1.


2a
Surf. of B.M. before test
Surf. of B.M. after test



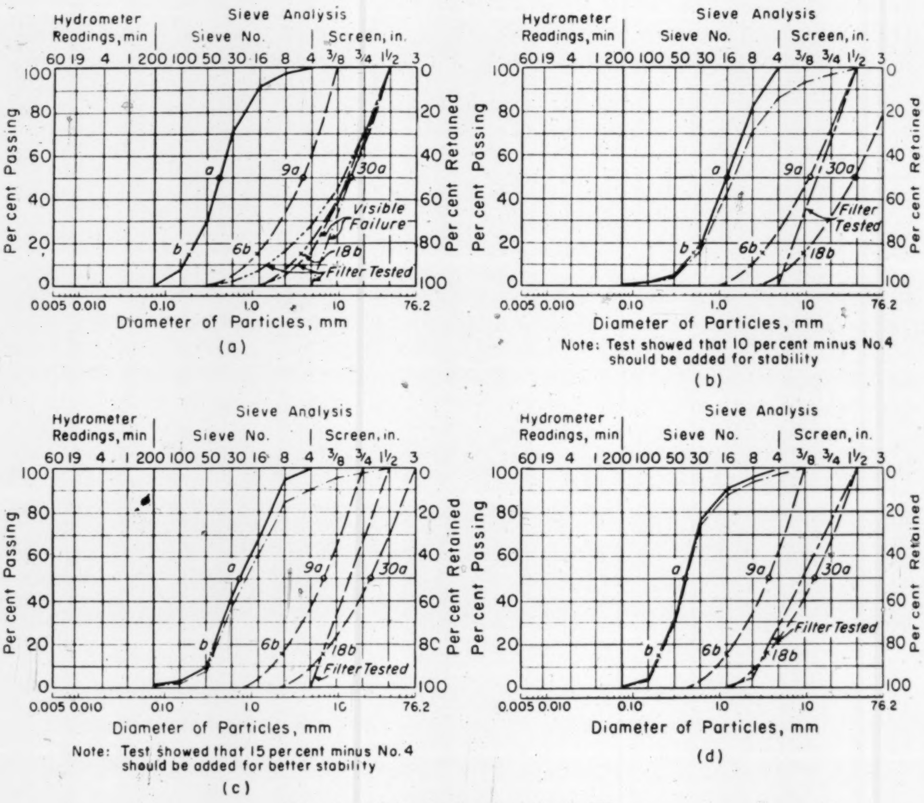
Filtration



Gradation

FIG. 8.—Graded Filter Series C_1, Check Test 2.

2. The filter material designed outside the coarse limit shown by this paper, but within the coarse limit of the other criteria,[2] showed a visible instability of the protective filter as may be seen in Fig. 8. The segregation of the base material and deep penetration of fines into the filter indicates that the selected ratio of 4.0 for 15 per cent size of filter material to 85 per cent of base material for this particular case is too high. This undoubtedly is a result of the broad range of this base material and insufficient consideration of fine in the base material, although the criteria may be satisfactory for a steeper base material curve. Therefore, the gradation curve of the filter has to have more skewness toward the fine sizes and this example indicates that criteria based on the fine sizes are necessary.



(a)

Note: Test showed that 10 percent minus No. 4 should be added for stability

(b)

Note: Test showed that 15 per cent minus No. 4 should be added for better stability

(c)

(d)

FIG. 9.—Criteria-Crushed Rock Filter.

After completion of all tests and considering the test results, it was concluded that the following rules should be met in designing of protective filters of natural subrounded material:

1. For uniform grain-size filters it is required that the ratio of the 50 per cent grain size of the filter material to the 50 per cent grain size of the base material should be between the limits of 5 and 10.

2. For graded filters it is necessary that the ratio of the 50 per cent grain size of the filter material to the 50 per cent grain size, R', of the base material should be between the limits 12 and 58. The

ratio of the 15 per cent grain size of filter material to the 15 per cent grain size of the base material, R'', should be between the limits 12 to 40.

In addition, the following requirements for graded filter should be met:

(*a*) The filter material should pass the 3-in. screen for minimizing particle segregation and bridging during placement. Also, filters must not have more than 5 per cent minus No. 200 particles to prevent excessive movement of fines in the filter and into drainage pipes causing clogging.

(*b*) The gradation curves of the filter and the base material should be approximately parallel in the range of finer sizes, because the stability and proper function of protective filters depend upon skewness of the gradation curve of the filter toward the fines, giving a support to the fines in the base material.

(*c*) The filter material adjacent to the drainage pipe should have sufficient coarse sizes to prevent movement of filter material into the drainage pipe. *The maximum size* of perforations or joint openings of the drainage pipe was selected as *one-half* of the 85 per cent grain size of the filter material.[3] This criterion has proven satisfactory in all filter tests conducted in the laboratory.

(*d*) In designing of filters for base materials containing particles larger than No. 4 size the base material should be analyzed on the basis of the gradation of material smaller than No. 4 size.

TEST RESULTS ON CRUSHED ROCK

Six laboratory filtration tests were made for a specific design study with filter test assemblies consisting of base material and crushed limestone filter material. These tests provided data for comparison of the functioning of various combinations of base and filter gradation, through observations and measurements of the rates of flow and pressure heads and determination of quantitative changes in base and filter materials which occurred during the tests. The various gradations tested and suitable gradation ranges established are shown in Fig. 9. It was found in these tests that visible failure occurred for two of the gradations of filter materials shown in Fig. 9(*a*). The failure of these two gradations which were within the limits for natural subrounded material indicated that finer gradations were needed for stability of crushed rock filters. Other crushed rock gradations tested, shown in Fig. 9(*b*), (*c*), and (*d*), provided some data on the basis of their satisfactory operating characteristics to select *tentative criteria limits for crushed rock*. These test results led to the following comments:

(*a*) The criteria developed for designing of graded filters from "Natural Subrounded Material" cannot be applied for designing filters from "Crushed Rock" because the crushed rock has a high degree of angularity and larger percentage of voids.

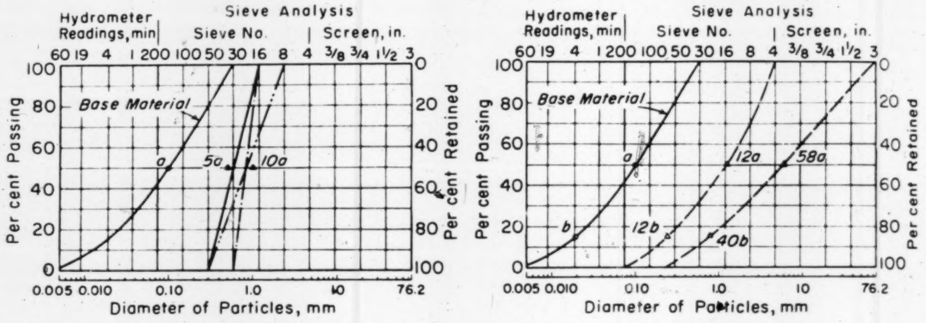
(*b*) A crushed rock filter, for protection of similar base materials, requires a material of finer gradation than that of the natural subrounded filter.

(*c*) On the basis of the tests it appears that a *tentative criteria* for designing graded crushed rock filters should have a numerical relationship between the gradation of base and filter materials as follows:

(*1*) The ratio of the 50 per cent grain size of the filter material to the 50 per cent grain size of the base material, R'_{CR} (crushed rock), should be between the limits 9 and 30.

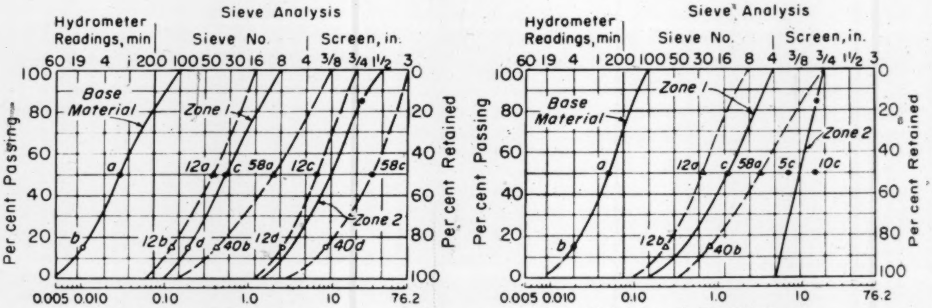
(*2*) The ratio of 15 per cent grain size of the filter material to the 15 per cent grain size of the base material, R''_{CR}, should be between the limits 6 and 18.

These studies have not provided enough data to separate filter materials into types such as uniform or graded materials, as was done in the previous filter research. The limits proposed in (*c*) above must be considered general until further detail can be obtained by more tests. Therefore, the information given in this article concerning the proposed criteria for designing protective filters from crushed rock must be considered as a preliminary study and the criteria are considered as a guide.



(a) Uniform Grain-size Protective Filter

(b) Graded Filter



(c) Graded Zoned Filter

(d) Zoned Filter Graded and Uniform Grain-size

*Maximum slot opening in pipes is equal to $\frac{85\%\ \text{size}}{2}$

FIG. 10.—Examples of Filter Design.

RECOMMENDATIONS FOR CONSTRUCTION

In order to prevent the failure of valuable engineering superstructures due to poorly controlled seepage water, engineers must be certain that a selected filter material of the desired gradation is properly placed during construction. The following recommendations are presented for the preparation of the subgrade and the placement of the filter material:

1. The subgrade before placement of filter material has to be slightly compacted by means of a light roller, or by other suitable compaction equipment and smoothed with a light flat roller or pneumatic roller. These measures are necessary for filling depressions and holes that might cause unequal settlement of a drain.

2. The clean filter material should

have sufficient moisture content (3 to 10 per cent) during placement to prevent segregation.

3. The filter material should be compacted in about 4-in. layers with light flat roller or, where space is limited, by hand tamping.

4. The filter layer should not be less than 8 in. in thickness. Where the subgrade consists of fine-grained soil a "zoned" or two-layer filter is usually required and the combined thickness of both layers should be at least 16 in.

5. The filter system must be sufficiently thick to act as an insulator where frost action is involved.

6. Where drainage pipe is used in a filter system, the capacity of the pipe should be sufficient to collect the seepage water and to conduct it to a place of discharge.

7. The size of the perforation and joint openings in the drain pipe should be made with consideration of the filter material as follows: Maximum opening = $\frac{1}{2}$(85 per cent size *FM*).[3]

While the pipe is being laid, the slots should be protected from inflow of fines of the filter material by burlap or other suitable permeable material.[4]

ILLUSTRATIVE EXAMPLES OF DESIGN

Four illustrative examples are presented in Fig. 10 for design of the different types of protective filter. These examples in successive order are as follows:

Uniform grain-size protective filter (Fig. 10(*a*)), indicating one of three gradations of filter is suitable to protect a given base material. The limits are controlled by the values of 5 and 10 times the 50 per cent grain size of the base material, point *a*.

Graded filter (Fig. 10(*b*)), showing limits between which any curve is acceptable provided consideration is given to shape so that it is approximately parallel to the base material curve for the finer sizes. These limits are controlled by the factors 12 and 58 for point *a* and 12 and 40 for point *b* on the base material curve.

Zoned filter—two layers of graded material (Fig. 10(*c*)). The first zone is designed on the basis of the points *a* by the factors 12 and 58, and *b* by 12 and 40, as shown, and a suitable filter material is established. The second zone is designed on the base of points *c* and *d* of the zone 1 filter using the same factors. The second zone will be next to the drain pipes and the maximum slot openings will be one-half the 85 per cent size of this filter material.

Zoned filter—graded and uniform grain-size material (Fig. 10(*d*)). The first zone is designed on the basis of the graded filter criteria using points *a* and *b* on the base material curve and the factors 12 and 58, and 12 and 40, and a suitable zone 1 gradation is established. The second zone is designed on the basis of the uniform filter criteria using point *c* on the zone 1 gradation and the factors 5 and 10. The second zone will be next to the drain pipes and the maximum slot openings will be one-half the 85 per cent size of this filter material.

CONCLUSIONS

Some of the objectives of this exploratory research program were to develop apparatus and equipment and procedures to determine suitable criteria for the design of the protective filters, which would be more applicable in the field. It is felt that these purposes have been adequately achieved in that equipment and techniques have been developed for the study of design problems. It is felt that the results obtained will be useful in the study of the particular field problems and will permit realistic recommendations for the solution of such problems.

Considering the four requirements

given in the introduction on page 1185, it is evident that a given base material can be protected by filter material within a certain range of gradation. This gradation should bear the following relationship to the base material:

1. *For uniform grain-size filters consisting of natural subrounded particles.* The ratio of the 50 per cent grain size of filter material to the 50 per cent grain size of the base material should be between the limits 5 and 10.

2. *For graded filters consisting of natural subrounded particles.* The ratio of the 50 per cent grain size of filter material to the 50 per cent grain size of the base material should be between the limits 12 and 58 and the ratio of the 15 per cent grain size of filter material to the 15 per cent grain size of base material should be between the limits 12 and 40.

3. *Tentative relationship for graded filter consisting of crushed rock.* The ratio of the 50 per cent grain size of filter material to the 50 per cent grain size of the base material should be between the limits 9 and 30 and the ratio of the 15 per cent grain size of filter material to the 15 per cent grain size of base material should be between the limits 6 to 18.

4. In addition to the limiting ratios established for adequate filter design, the four requirements given on page 1195, concerning (*a*) maximum size of filter material, (*b*) shape of gradation curve, (*c*) maximum size of drain pipe openings and (*d*) base material containing gravel, should be met.

The described criteria for designing protective filters is used by the Bureau of Reclamation in design of inverted filters for canal slopes protection and drainage systems under concrete canal linings, canal structures, and spillways.

Acknowledgment:

The author's sincere appreciation is extended to colleagues in the Bureau of Reclamation, W. G. Holtz, Chief of the Earth Laboratory, H. J. Gibbs, Engineer, C. W. Jones, Engineer, R. S. McMechen, Engineering Aid, for their interest in the work and technical assistance.

SOIL DENSITY DETERMINATION BY DIRECT TRANSMISSION OF GAMMA RAYS*

BY R. K. BERNHARD[1] AND M. CHASEK[2]

SYNOPSIS

The significant question raised in this study is whether the standard, rather destructive procedures for determining soil densities can be supplemented or replaced by less destructive or nondestructive methods. As a particular objective an investigation on soil density determination by means of gamma-ray transmission was undertaken. Experiments in the laboratory and in the field are described.

A radiation source of 60 millicurie (irradiated cobalt 60) and a radiation detector, comprised of a scintillation head in combination with a binary counter, were available. Fourteen different soils, characteristic of the state of New Jersey, were investigated under various compaction and moisture conditions.

Equations could be derived relating soil density as the unknown variable, transmitted radiation energy through the soil as a measurable variate, and distance between radiation source and detector as an arbitrarily selected variable.

Further studies are recommended to investigate the relationship between absorption coefficients, primary rays, and scattering effects as well as the development of smaller and more durable equipment for field use.

The difficulties in determining soil densities by the standard sand-cone or similar methods are well known. These difficulties may be summarized as follows:

1. The methods are time consuming and require rather experienced and conscientious technicians.

2. The methods cannot be considered as fully nondestructive, especially when density determinations at more than 2-ft depth require considerable excavations for handling of the sand cone.

3. The methods do not permit a continuous recording, which might become valuable in case of rapidly changing soil densities due to moisture content or compaction.

4. Most of the methods are not applicable to dry, noncohesive sand—for example, beach sand.

5. The methods represent at best a spot-check method. A sample of less than $\frac{1}{10}$ cu ft is blown up to a value referring to 1 cu ft. Therefore, a considerable number of spot checks must be made to reduce the statistical error.

Since soil, in general, is a nonhomogeneous material, the inherent deficiency of a spot-check method (Item 5) seems to be the most objectionable. In other words, variations in soil densi-

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ties within a small area will yield erratic results which might be of no significance with respect to the over-all bearing capacity of the soil. Hence, the main purpose of this investigation is to study a method which avoids some of the above listed difficulties by using a system which permits an integration of soil densities over larger volumes. It must be kept in mind, however, that such an integration also has definite upper limits. This is of particular importance if pockets of loose or dense material are predominant, thus preventing the proper functioning of the soil as a supporting agent.

Previous experiments (**1** to **4**)[3] with radioactive isotopes have shown that the intensity of radiation transmitted through soils depends mainly upon the density of the soil. Theoretical considerations, including the basic physical concepts are described elsewhere (**4**). Preliminary experiments indicated that it was necessary, first, to raise the energy level of an irradiated cobalt 60 source of 12 millicuries and, second, to increase the sensitivity of the then available rate meter and Geiger tube. Both aims were achieved by securing a cobalt 60 radiation source of 60 millicuries and by using a highly responsive scintillation detector, the most sensitive instrument available at present. With this improved equipment the main objectives could be obtained,—to enlarge the distance between radiation source and radiation detector from 2 to 7 ft in the laboratory and from 2 to 4 ft in the field.

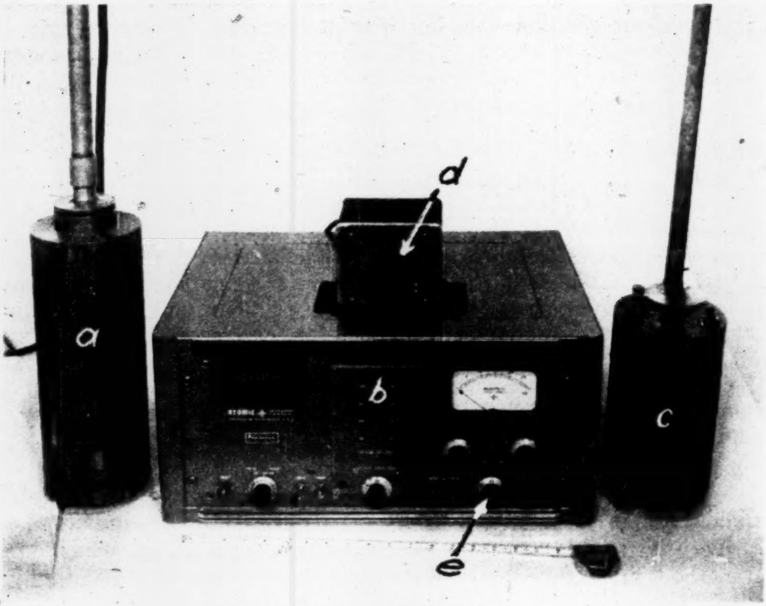

FIG. 1.—Instrumentation Assembly.
(*a*) isotope container; (*b*) binary scaler; (*c*) pickup unit; (*d*) preset timer; (*e*) pulse height discriminator.

Furthermore, a pilot study in the laboratory on the effect of scattered radiation could be made. A more detailed investigation might become of primary importance for larger distances between radiation source and radiation detector.

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[3] The bold face numbers in parentheses refer to the list of references appended to this paper, see p. 1215.

EXPERIMENTAL CONSIDERATIONS

Instrumentation:

Radiation Source.—A radiation source in the form of a radioactive cobalt wire, $2\frac{3}{8}$ in. long and $\frac{1}{8}$ in. in diameter, was obtained. This wire was originally irradiated by the Brookhaven National Laboratory up to an energy level of 70 millicuries. According to the half-life decay value for cobalt 60 (5.3 yr) this energy had decreased after 15 months to the present level of approximately 60 millicuries (see Appendix).

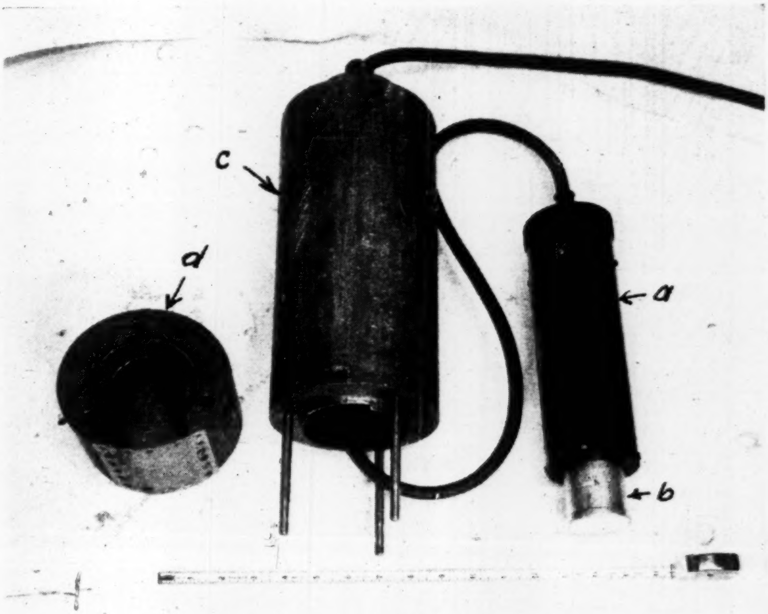

FIG. 2.—Detector Unit, Disassembled.
(*a*) scintillation head; (*b*) Na(Tl)—scintillation crystal; (*c*) lead shield—upper part; (*d*) lead shield—lower part (collimator).

Radiation Detector.—A binary scaler, equipped with a preset timer (Fig. 1), was available having four counting ranges, up to $2^4 \times 10^6$, $2^6 \times 10^6$, $2^7 \times 10^6$, and $2^8 \times 10^6$ pulses. For most experiments the highest range, $2^8 \times 10^6$ counts, was selected.

Pickup Unit.—In combination with the above scaler a pickup unit was used, comprised mainly of the following parts: a scintillation crystal (sodium iodide-thallium activated), 2 in. in diameter and $1\frac{3}{4}$ in. in height; a photomultiplier tube; and a preamplifier (cathode follower) (Figs. 2 and 3). The pick-up unit could be placed in a lead shield in the form of a cylinder with outside dimensions of $5\frac{1}{4}$-in. diameter and 16-in. total height. This lead shield was necessary for the following reasons: (*a*) to reduce the transmission of background noise primarily due to cosmic rays; (*b*) to protect the shock sensitive scintillation crystal and photomultiplier tube; and (*c*) to form a collimator (Fig. 3(*b*)) acting as directional shield

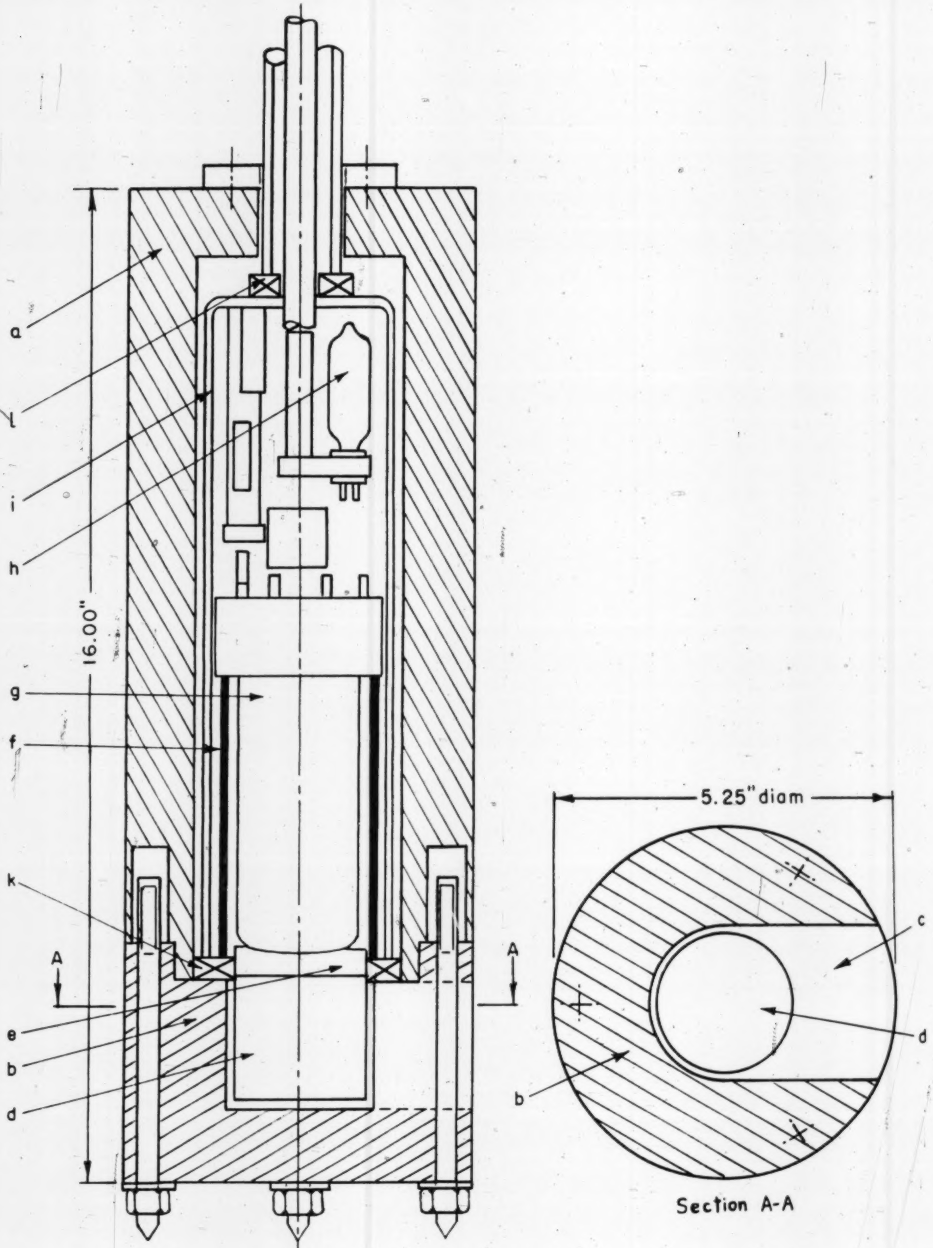
a
l
i
h
16.00"
g
f
k
A
A
e
b
d
5.25" diam
c
d
b
Section A-A

FIG. 3.—Detector Unit—Cross-Sections.

(*a*) lead shield—upper part; (*b*) lead shield—lower part; (*c*) opening in *b* acting as collimator (directional shield for side exposure); (*d*) Na (Tl)—scintillation crystal; (*e*) light pipe; (*f*) metal shield; (*g*) photomultiplier tube, (*h*) preamplifier (cathode follower); (*i*) housing for *d* to *h*; (*k*) and (*l*) rubber rings.

and restricting the crystal to essentially side exposure only.

Calibration.—An independently calibrated radiation source of cobalt 60 with a low energy level of 7.83 × 10^{-4} millicurie was placed at a rigidly fixed distance 1 ft from the detector. This calibration had to be repeated at regular intervals to check whether the scaler-pickup combination reproduced accurately the once established standard (counts per min on register).

Pulse Height Control.—The gamma photons incident on the scintillation crystal govern the number of pulses registered by the counter. The setting of an adjustable pulse height control knob on the scaler (*e*), Fig. 1, determines the minimum voltage level of pulses picked up by the scintillation head. At distances between radiation source and detector of less than 3 ft, the mechanical parts of the counter do not react fast enough to respond to the rapid sequence of pulses for the normal setting of the pulse height discriminator. Hence, an increase in minimum pulse height level had to be established. In Fig. 5 the correction factors are shown that are necessary to correlate readings taken at various pulse height level settings.

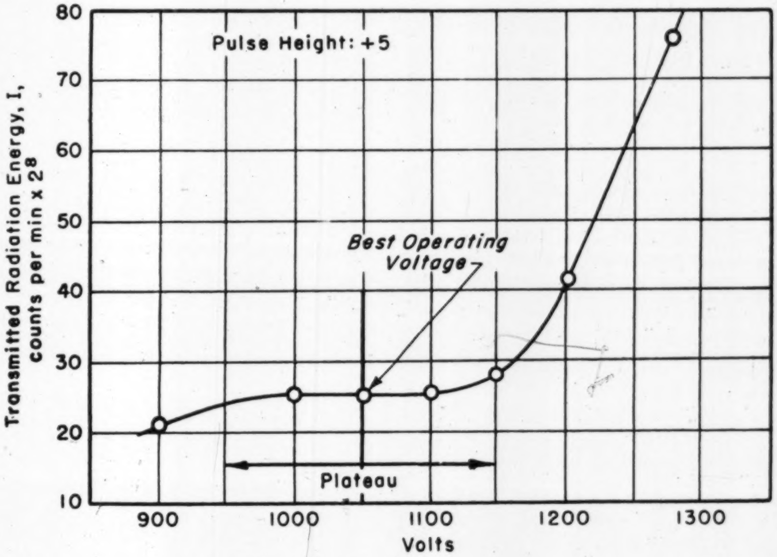

FIG. 4.—Plateau Characteristic of Detector.

Plateau Characteristics.—Existing variations in the line voltage produce transients in the high-voltage power supply of the scaler. These transients have to be reduced so that the scintillation tube is not affected. A high-voltage range, the so-called plateau, exists where a change in line voltage does not increase or decrease the registered counts per min. Figure 4 indicates that 1050 v is the approximate center of this plateau, hence the best operating range. This voltage has been used throughout all experiments.

Radiation source and detector were placed 15 in. below the surface of a large bed of Croton soil (Table I). The values recorded for distances between radiation source and detector of 2 and 3 ft are almost identical.

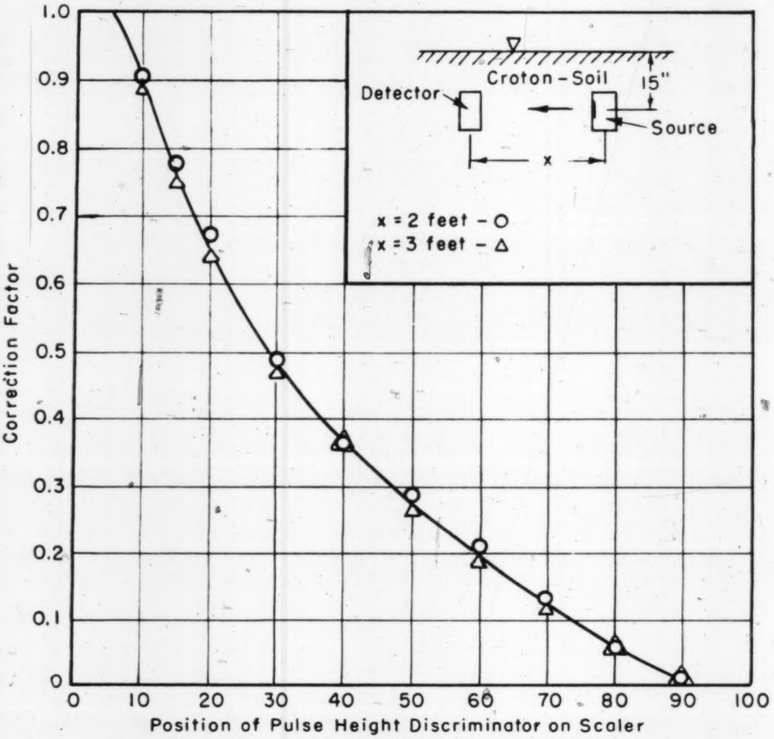

FIG. 5.—Correction Factors for Various Pulse Heights.

TABLE I.—ENGINEERING CHARACTERISTICS OF SOILS INVESTIGATED (**5**).

Name	Sieve Designation, Cumulative Per cent Passing					Hydrometer Analysis		Consistency Limits, Minus No. 40[a], per cent		Compaction Proctor		Highway Research Board Designation	
	¾ in.	No. 4	No. 10	No. 40	No. 200	Silt, per cent	Clay, per cent	Liquid Limit	Plastic Limit	Maximum Density, lb per cu ft	Optimum Moisture Content, per cent	Sub-Grade Group	Group Index
1. Beach	100	100	100	73	0	0	0	NL	NP	106	11	A-3	0
2. Riverton	100	100	100	34	12	8		NL	NP	109	12	A-2-4	0
3. Pennsylvania	94	76	63	46	35	16	19	31	7	106	7	A-2-4	0
4. Dunellen	100	98	95	76	27	...	...	16	0	120	12	A-2-4	0
5. Gloucester	96	90	86	79	56	31	21	25	6	109	16	A-4	4
6. Sassafras	99	95	93	79	42	20	21	28	12	117	14	A-6	2
7. Hagerstown	100	99	98	92	83	42	34	43	20	101	20	A-7-6	13
8. Elkton	99	97	95	89	79	45	31	28	10	108	16	A-4	8
9. Croton	97	80	73	68	64	23	27	41	21	100	21	A-7-6	15
10. Portsmouth	99	87	84	56	7	...	...	NL	NP	118	10	A-3	0
11. Holyoke	99	98	96	89	60	32	20	27	12	116	14	A-6	6
12. Washington	93	88	85	76	64	25	36	31	10	104	18	A-4	6
13. Sub-base Farrington	93	86	78	36	10	...	...	NL	NP	120	12	A-1-6	0
14. Sub-base Jamesburg	94	78	71	41	2	...	...	NL	NP	108	16	A-1-6	0

[a] NL = non-liquid. NP = non-plastic.

Effect of Scintillation-Head Shield.—A series of experiments were made to determine the effect of the scintillation-head shield: First, with the complete lead shield, *a* and *b*, Fig. 3, second, with the lower part, *b*, of the lead shield alone, and third, with no lead shield.

Figure 6 indicates that at a distance of 3 ft between energy source and detector no significant difference exists in all three cases. The background level readings, however, change substantially. At 3-ft distance and 120-lb per cu ft soil density, the difference between background level and readings without shielding becomes rather small. For this reason all further experiments were made with both the upper and the lower shield enclosing the scintillation head.

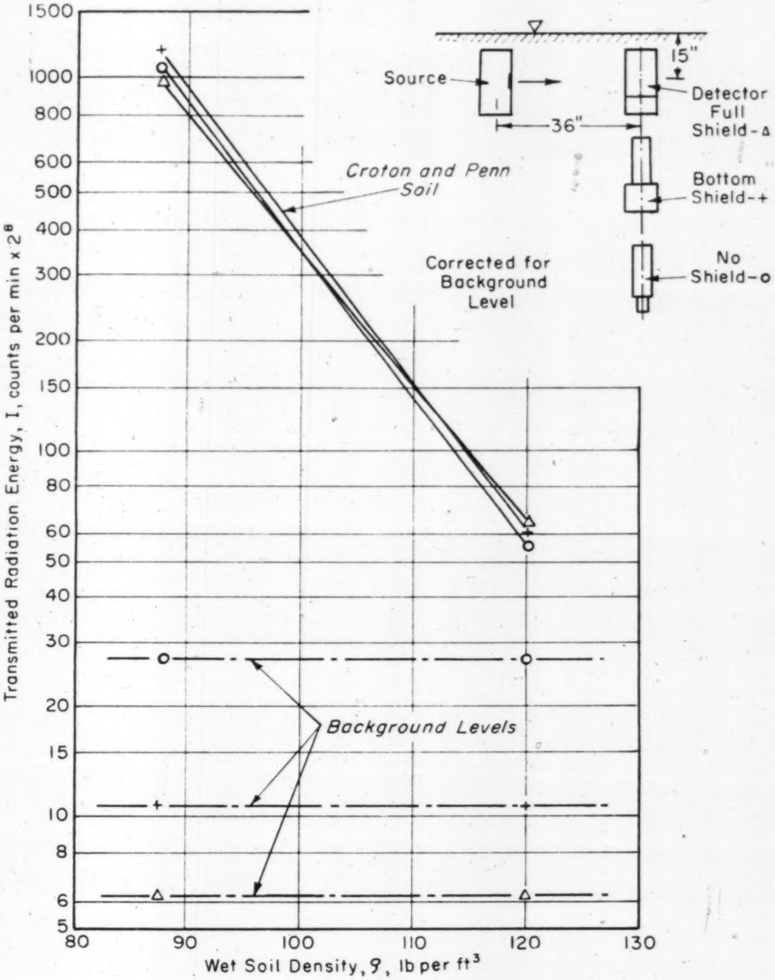

FIG. 6.—Effect of Lead Shields on Detector.

Safety Precautions:

Tolerance Dose.—All safety precautions were strictly observed to prevent any radiation beyond the permissible tolerance dose of 7.5 milliroentgens per hr (300 milliroentgens for a 40-hr week) as set by the Atomic Energy Commission and other agencies.

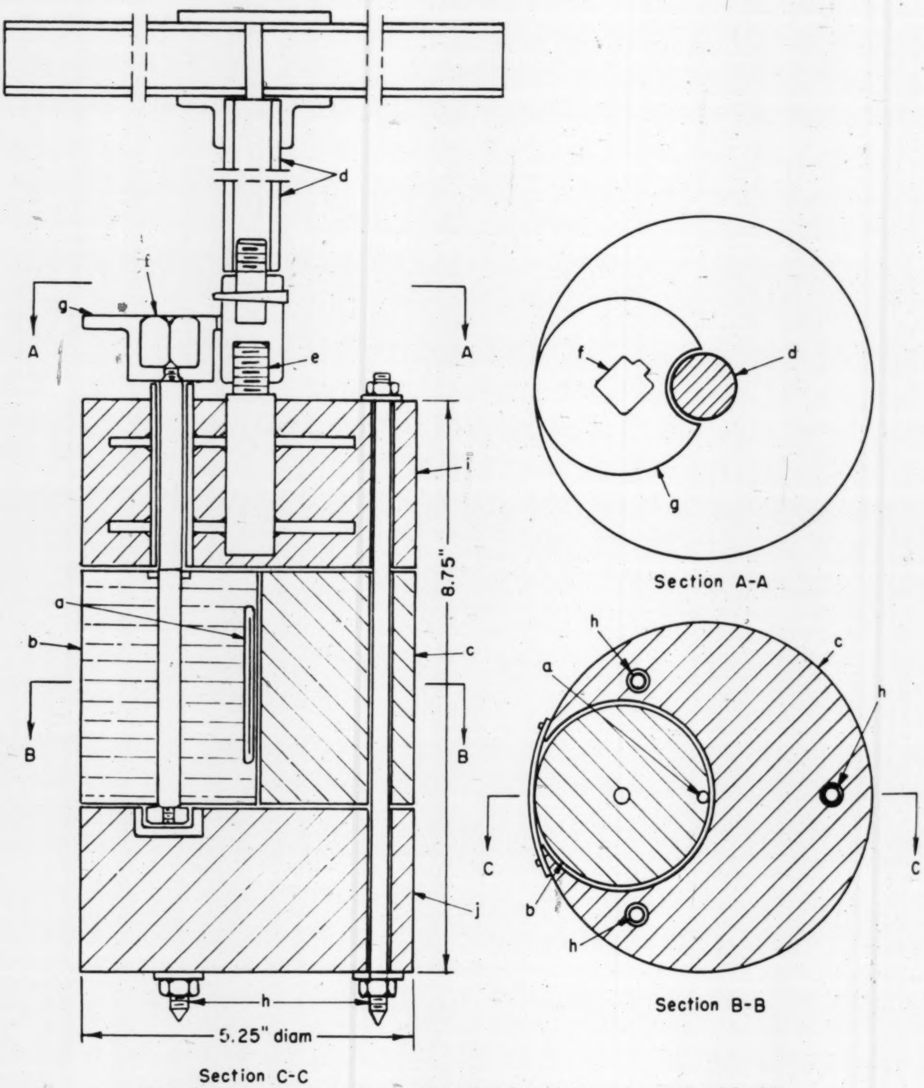

FIG. 7.—Isotope Container—Cross Sections (Nonexposure Position).

(*a*) Irradiated cobalt wire; (*b*) inner lead cylinder; (*c*) outer lead cylinder—central part; (*d*) handle to transport container and to rotate *b*; (*e*) threaded stud for *d* to transport container; (*f*) squared hole for *d* to rotate *b*; (*g*) locking disk; (*h*) assembly bolts; (*i*) upper lead cylinder; (*j*) lower lead cylinder.

Health Survey.—Every operator was required to carry a dosemeter in his breast pocket and watch closely that the above tolerance dose was never approached. In addition monthly blood counts were prescribed.

Radiation Source Container.—A special radiation source container was built including mechanical interlocking devices to prevent, as much as possible, improper handling of the radioactive source. This container (Fig. 7), weighing approximately 75 lb, served as a storage and exposure holder. The radiation sources fitted into a slot, *a*, on the surface of a 2.75-in. diameter, rotatable lead cylinder, *b*. This cylinder was located eccentrically within a second 5.25-in. diameter lead cylinder, *c*.

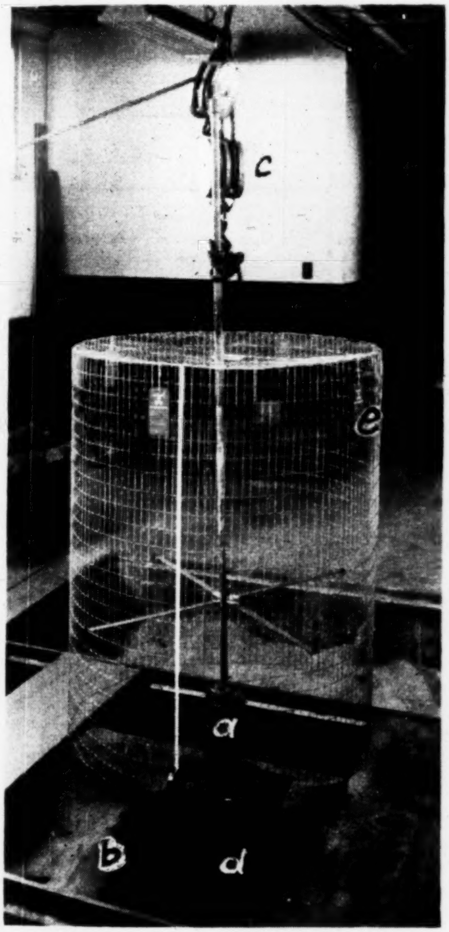

FIG. 8.—Experimental Set-Up in Soil Basin.
(*a*) Isotope container; (*b*) soil in basin; (*c*) hoist to hold *a* at required depth in *b*; (*d*) thin steel pipe inserted in *b* to lower *a*; (*e*) wire cage.

In the "closed", transport or storage position, a minimum of 2.5 in thick. lead surrounded the radiation source in all directions. In the closed position, the tolerance dose (7.5 milliroentgens per hr) of the 60-millicurie source was reached at a 14-in. distance measured from the center of the container. A light wire cage 44 in. in diameter prevented any accidentally closer approach (Fig. 8). The safe distance was determined theoretically (see Appendix) and verified experimentally by survey meter readings. In Fig. 9 these results are plotted. The experimentally determined curve of the distance (inches) between radiation source and survey meter *versus* radiation dose (milliroentgens per hr) agrees closely with the theoretical dose derived from the definition: 1 millicurie = 1.35 milliroentgens per hr at 1-m distance (Appendix).

EXPERIMENTAL DATA

The main purpose of the experiments was to develop equations that permit a soil density determination from transmitted radiation energy readings for any source-detector distances. Counts were registered using time periods from 2 to 10 min, depending upon the count-rate. For low count-rates a larger period was selected in order to minimize the statistical error. For high count-rates either smaller periods were selected or the pulse height discriminator was adjusted to count larger pulses only.

Soils:

Fourteen different soils were investigated. Their characteristic qualities are summarized in Table I. Previous tests (**4**) showed that the transmitted radiation energy when plotted against wet soil density is independent of the moisture content. Hence, all the following soil density data refer to wet density.

Laboratory Tests:

Density versus Counts Per Min.—A rigid wooden soil container was built, capable of sustaining a soil sample with the maximum dimension of 7 by $1\frac{1}{2}$ by $1\frac{1}{2}$ ft. (Fig. 10). Soils were poured as loosely as possible into the container using 6-in. layers. The density could be increased to any required value by vibrating the soil with a standard concrete vibrator. Either from the volumetric change, that is, the reduction in height of the soil surface within the container or by the sand-cone method (AASHO Designation T 147 - 49) the obtained density was computed. The distance between radiation source and detector had to be carefully measured. Distances from 2 to 7 ft were investigated. Results for beach sand and Penn loam are summarized in Fig. 11. Plotted on the *X*-axis is the wet density, ρ, in lb per cu ft, using a linear scale and on the *Y*-axis the transmitted radiation energy, I, in counts per min $\times\ 2^s$, using a logarithmic scale. All results indicate a linear relationship between $\ln I$ and ρ, regardless of the source-detector distance. However, at distances of 4 ft and larger the slopes of these lines decrease.

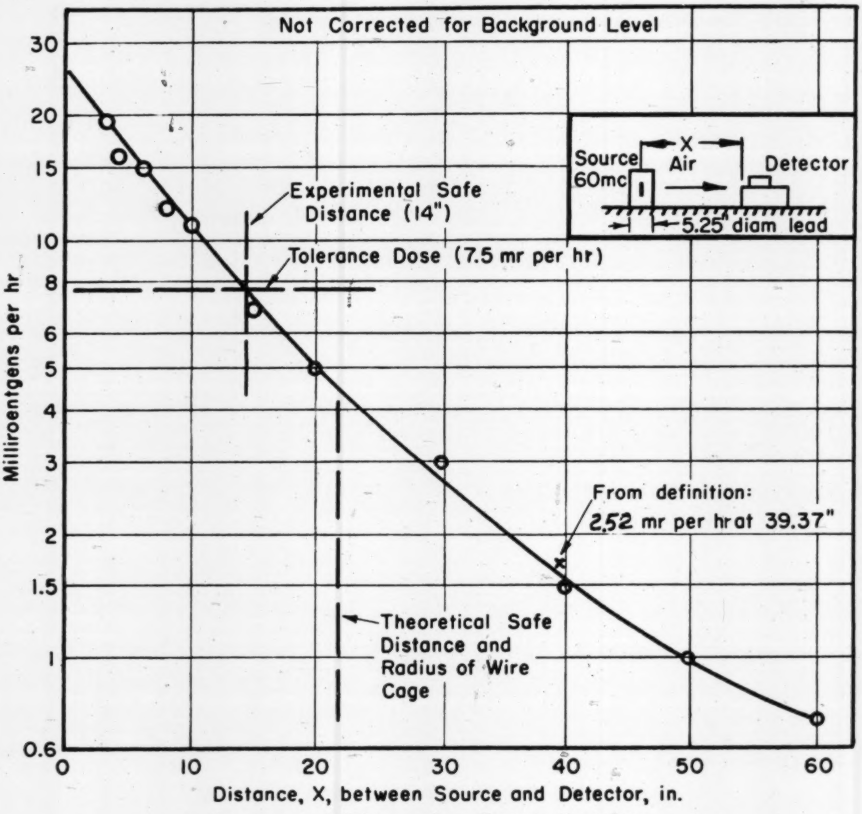

FIG. 9.—Safe Distance from Isotope Container.

To determine the reason for this decrease in slope, experiments were made by measuring the scattering effect, first through air and second through soil. In both cases the primary beam was absorbed by placing a shield, 4 by 8 by 12 in., consisting of six lead bricks, between source and detector at a fixed distance. Only the position of the detector was varied.

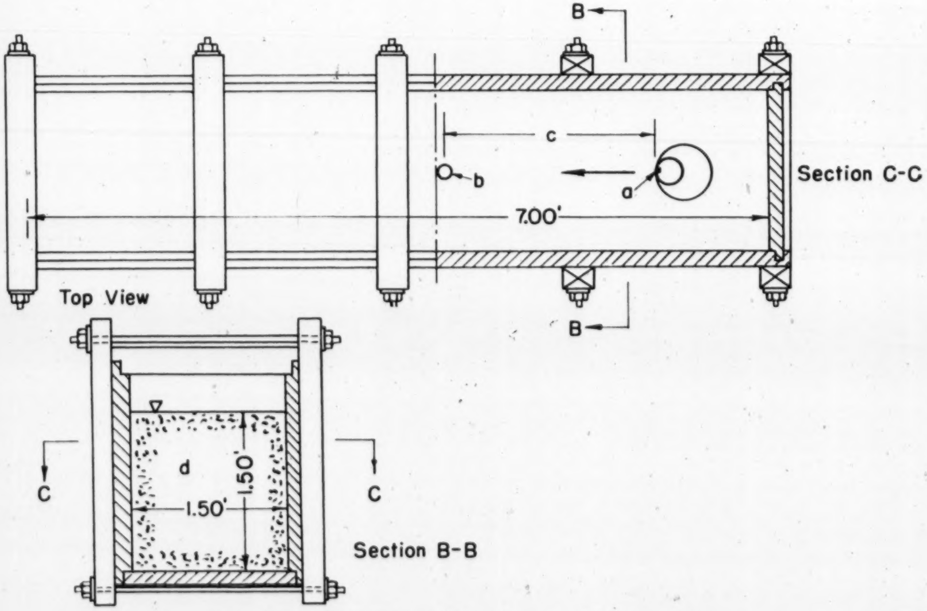
B
B
c
b
a
7.00'
Section C-C
Top View
d
1.50'
1.50'
C
C
Section B-B

FIG. 10.—Soil Container for Laboratory Experiments.

(*a*) radiation source; (*b*) radiation detector; (*c*) variable distance between *a* and *b*; (*d*) soil sample.

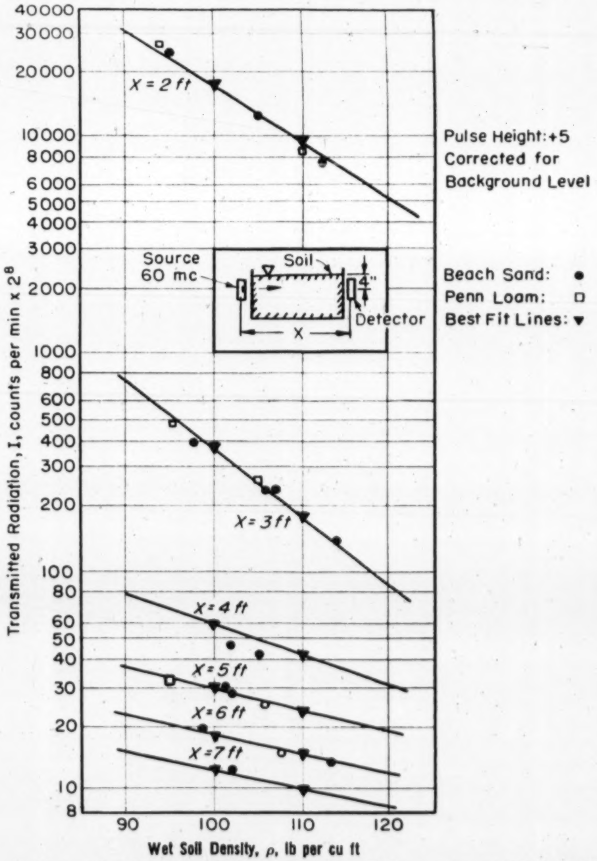

FIG. 11.—Transmitted Radiation Energy *versus* Wet Soil Density For Various Source-Detector Distances (*x*).—Laboratory Experiments. Best Fit Lines.

Scattering Through Air.—Figure 12 shows the experimental set-up and results. At 60-in. distance, x, between lead bricks and detector, maximum scattered radiation, I, is reached.

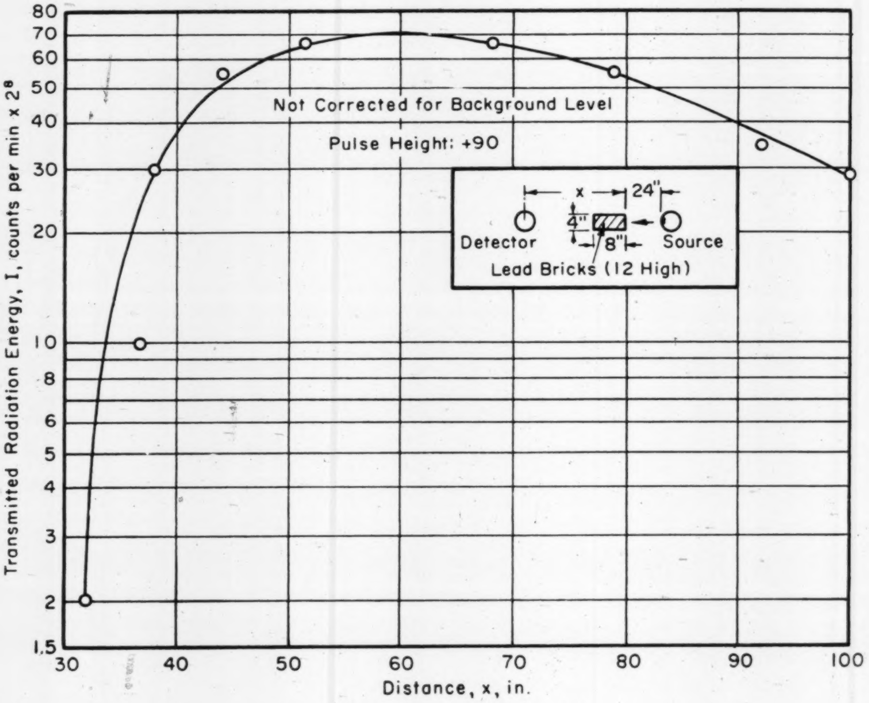

FIG. 12.—Scattering Effect in Air.

Scattering Through Soil.—A similar arrangement using beach sand as absorber medium is shown in Fig. 13 and represents the transmitted radiation with and without the lead bricks. It is noticeable that for distances between source and detector larger than 3.80 ft, the primary beam becomes less than the background level of 6×2^8 counts per min. For distances of more than 4 ft the measured radiation is essentially due to scattering effects.

Analysis of Laboratory Tests.—Laboratory tests indicated that scattering from the walls of the wooden container as well as from the walls and floor of the laboratory predominates at source-detector distances of more than 4 ft. In this case larger cross-sectional areas of the sample to be calibrated are required.

The equation of the primary beam can be written in the form:

$$\ln I_{\text{primary}} = 23.22 - 2.60 \ln x - 0.0306\,(\rho x) \quad \text{..(1)}$$

where:

I_{primary} = transmitted radiation energy in counts per min,
x = source-detector distance in ft, and
ρ = wet soil density in lb per cu ft.

The following additional equation representing the scattering effect for these particular geometrical conditions was used as a temporary expedient:

$$\ln I_{\text{scattering}} = 18.24 - 2.40 \ln (\rho x) \quad (2)$$

Finally

$$I_{\text{total}} = I_{\text{primary}} + I_{\text{scattering}} \quad (3)$$

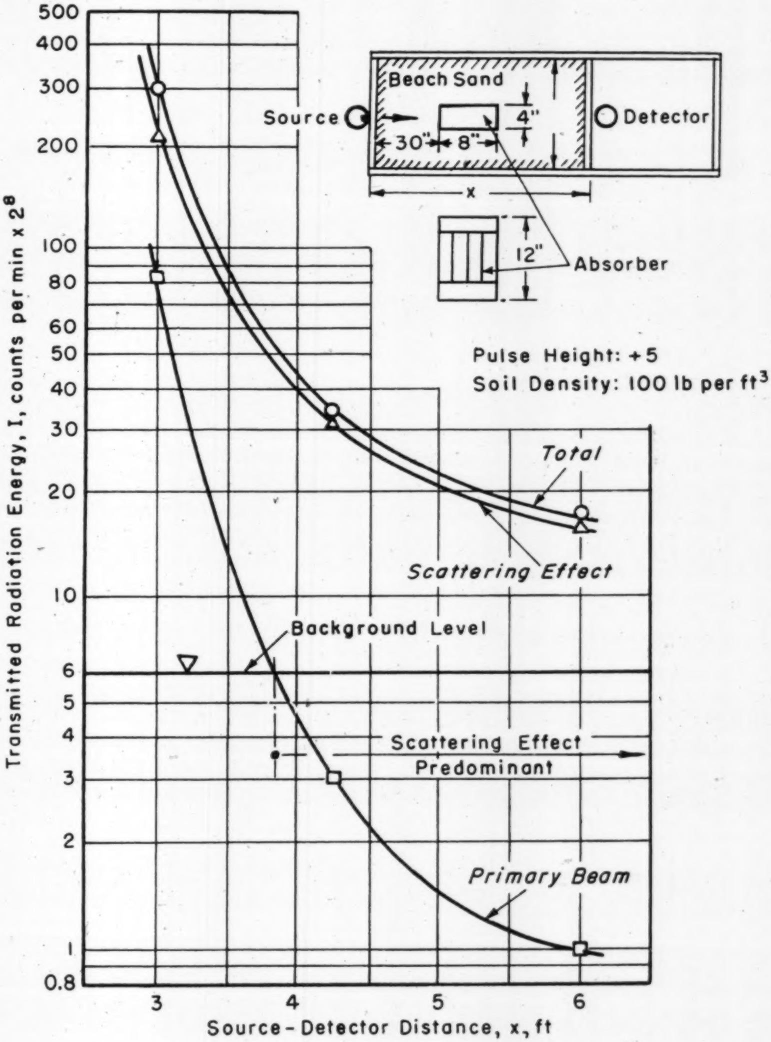

FIG. 13.—Scattering Effect in Soil.

Equations 1 and 2 are developed by means of statistical analysis, which is not included in this paper (6).

The "best fit" lines according to Eqs 1, 2, and 3 are plotted in Fig. 11 with a standard error of estimate of 0.1159. The experimentally determined values do not deviate more than ±3 lb per cu ft from these lines.

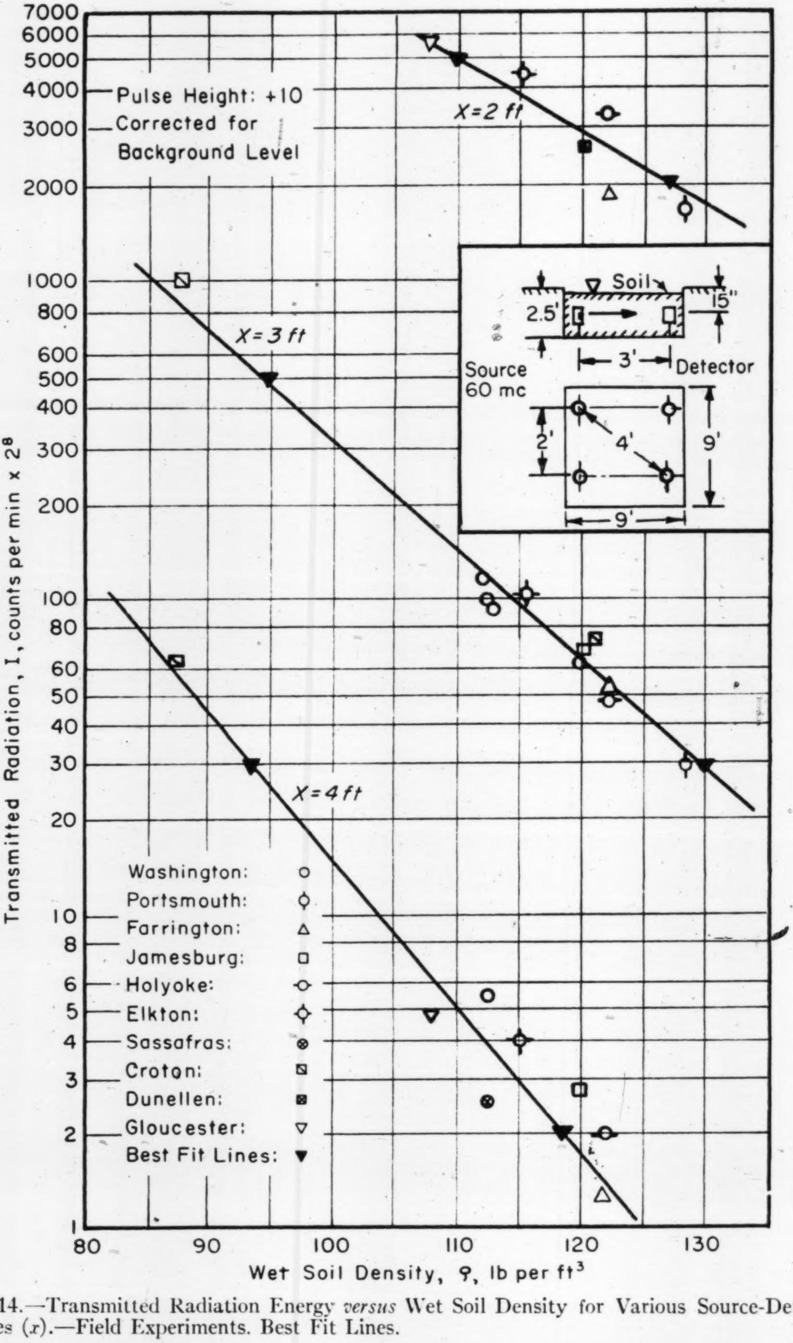

FIG. 14.—Transmitted Radiation Energy *versus* Wet Soil Density for Various Source-Detector Distances (x).—Field Experiments. Best Fit Lines.

Field Tests:

Two types of field experiments were made, first to compare the results from various types of soils and, second, to evaluate the change in soil density due to compaction.

Effect of Various Types of Soils.—Eleven different soils listed in Table I under Nos. 3 to 6 and Nos. 8 to 14 were available (**5**). Ten pits, approximately 9 ft square and 2.5 ft deep, had been dug into the natural ground (Penn loam). Each pit was filled with one of the soil samples and compacted in 6-in. layers by pneumatic tampers up to the surrounding ground surface. Radiation source and detector were lowered 15 in. below the soil surface, and intensity readings were taken at distances of 2, 3, and 4 ft between radiation source and detector (Fig. 14). Wet soil densities, ρ, could be determined with the standard sand-cone method. An average of two and more measurements of wet soil density, ρ, was plotted *versus* the transmitted radiation energy, ln I, (Fig. 14). All results again show a linear relationship between ln I and ρ, regardless of the type of soil and of the source-detector distances, x. In contrast to the laboratory experiments (Fig. 11), however, increasing slopes of the ρ *versus* ln I lines with increasing x become noticeable, indicating a predominant effect of the primary ray.

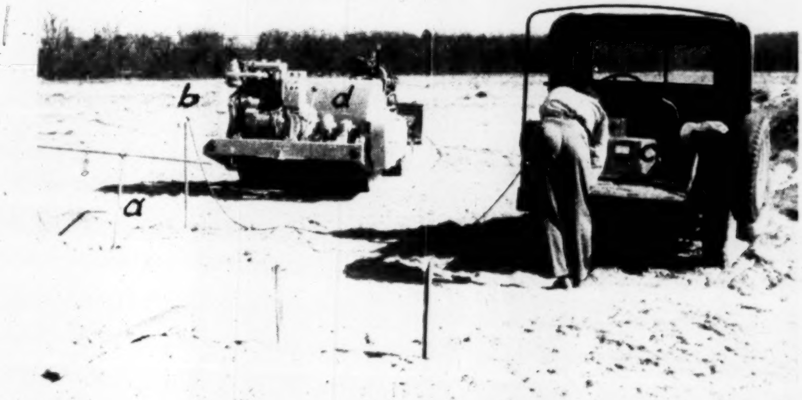

FIG. 15.—Soil Density Determination in the Field.

(*a*) extension and locking device for isotope container; (*b*) holder of detector for transmitted radiation energy from a (*c*) recorder to count radiation energy transmitted to (*b*) detector; (*d*) vibratory roller to compact soil.

Effect of Degree of Compaction of Soil.—A vibratory roller, *d*, Fig. 15, weighing 3 tons was available. This roller is comprised of two parts: a roller of 3.94-ft diameter and 4.67-ft width and an independent vibration exciter, which superimposes on the static effect of the roller a vibratory rotating force vector of 7 tons at 1600 rpm. The vibrator is driven by a 25 hp diesel motor with a self starter. The complete unit was pulled by a tractor.

Tests were made on a 4 ft high fill of Riverton soil (Table I (2)). Source and detector were buried 2 ft below the surface of the soil, 3 ft apart. Counts were registered before compaction, after the second and fourth pass of the vibratory roller and compared with the corresponding sand-cone density measurements.

Figure 16 indicates the results and plotted again are the ρ *versus* ln I values. The solid line repeats the corresponding "best fit" line for $x = 3$ ft in Fig. 14. The limited amount of experiments does not permit definite conclusions.

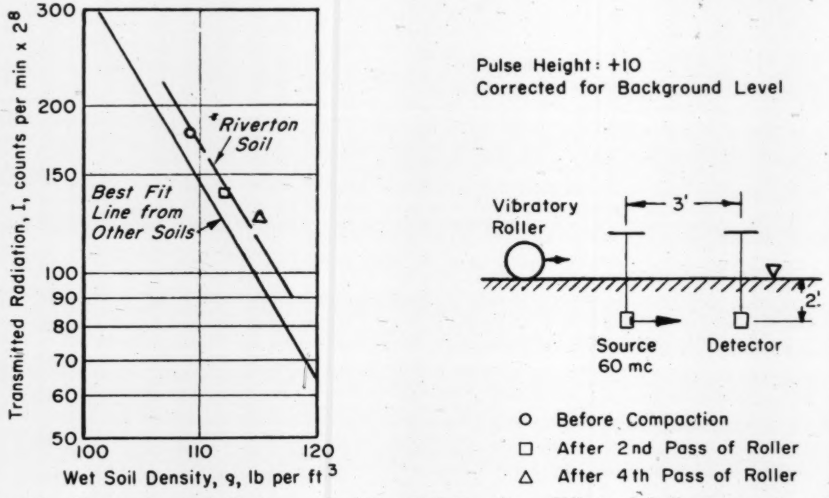

FIG. 16.—Transmitted Radiation *versus* Wet Soil Density.—Effect of Soil Compaction. Field Experiments.

Analysis of Field Tests.—The first series of field experiments yielded the following equations:

$$\ln I = 20.881 - 1.402 \ln x - 0.0266 (\rho x) \quad . . (4)$$

or

$$\rho = \frac{786}{x} - 37.59 \frac{\ln I}{x} - 52.71 \frac{\ln x}{x} \quad . . (5)$$

Equation 4 is developed by means of statistical analysis (6) as in Eq 1. The "best fit" lines according to Eqs 4 and 5 are plotted in Figs. 14 and 16 with a standard error of estimate of 0.251. The experimentally determined values do not deviate more than ±5 lb per cu ft from these lines.

Both series of field experiments indicate that the soil density determination by direct gamma-ray transmission can be adapted for field applications. One special example is the measurement of compaction effects as described above. The transmitted radiation energy seems to be almost independent of the composition of the soil, at least for the fourteen types of soils investigated so far.

CONCLUSIONS

1. The wet soil density is inversely proportional to the logarithm of the transmitted radiation energy.

2. A statistical analysis (6) of the experimentally obtained data yielded numerical values for density equations comprising the wet soil density as an unknown variable, the transmitted radiation energy as an observed variate and the distance between radiation source and detector as an arbitrarily selected variable.

3. With the equipment used, the direct radiation method allows integration of soil densities for a maximum distance between radiation source and detector in the field up to 4 ft and in the laboratory up to 7 ft.

4. Laboratory experiments require careful consideration of the geometrical conditions. Cross-sectional dimensions of the soil sample ought to have approximately the same width and height as the distance between source and detector.

5. Further studies are recommended to:

(*a*) Determine the effect of soil compaction,

(*b*) Investigate the relationship between absorption coefficient, primary rays, and scattering effect,

(*c*) Develop smaller and more rugged equipment for field use.

Acknowledgment:

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(3) Symposium on Use of Radioisotopes in Soil Mechanics, Am. Soc Testing Mats. (1952). (Issued as separate publication *ASTM STP No. 134*.)

(4) R. K. Bernhard and M. Chasek, "Soil Density Determination by Means of Radioactive Isotopes," *Nondestructive Testing* Vol. XI, No. 8, Nov.–Dec., 1953, p. 1723; Vol. XII, No. 1, Jan.–Feb., 1954, p. 40.

(5) F. C. Rogers and H. C. Nicola, "Frost Action Studies of Thirty Soils in New Jersey," Symposium on Frost Heave and Frost Action in Soil, Highway Research Board, 1951. (Issued as special publication.)

(6) R. K. Bernhard and M. Chasek, "A Statistical Analysis from Experiments with Gamma Ray Transmission Through Soils," *Second Progress Report*, Bureau of Engineering Research, Rutgers University, July, 1954, 25 pp. (Mimeographed copies available; further publication pending.)

APPENDIX

Determination of Radiation Source Decay:

The decay of the radiation source follows the exponential equation:

$$I = I_o e^{-\alpha t} \quad \text{(6)}$$

where:

I = decayed intensity in millicuries,
I_o = original intensity = 70 in millicuries,
"half-life" value = 5.3 yr for cobalt 60, and
t = elapsed time since irradiation = 1.25 yr.

From $e^{-x} = 0.5$ it follows that $x = +0.69$, or $0.5 = e^{-0.69}$; from $5.3\alpha = 0.69$, it follows that $\alpha = \frac{0.69}{5.3} = 0.13$. Hence Eq 6 yields:

$$I = 70e^{-0.13 \times 1.25} \doteq 60 \text{ millicuries},$$

that is, the original cobalt 60 source of 70 has decayed to 60 millicuries.

Required Safe Distance from Radiation Source:

Tolerance Dose: 7.5 milliroentgens per hr (300 milliroentgens for a 40 hr week)
Energy Source: cobalt 60—∼60 millicuries
Lead Shield: 2.5 in.
Absorption Half Value for Lead: 0.5 in.
Absorption through Lead Shield: $60 \times (\frac{1}{2})^{5.5}$—∼1.87 millicuries
Relation between millicuries and milliroentgens per hr:

By definition: 1 millicurie produces 1.35 milliroentgens at 1 m distance; hence 1.87 millicuries produces 2.52 milliroentgens per hr at 1 m distance (see Fig. 9).

Variation with Distance (d):

$$\text{milliroentgen per hr} = \frac{1.35 \times 1.32}{d^2 \text{ (meter)}} = 7.5,$$

or

$$d = \sqrt{\frac{1.35 \times 1.87}{7.5}} = 0.58 \text{ m} \doteq 22.8 \text{ in.}$$

Hence, the minimum safe distance from the outside of the lead container is 23 in.

DISCUSSION

MR. GEORGE F. SOWERS.[1]—What will it cost per hour or per day to make density determinations once the equipment is available?

MR. R. K. BERNHARD (*author*).—The costs must include, first, salaries of one technician and possibly one helper and, second, funds for upkeep and amortization of the equipment, and eventual replacement of the source after it has decayed below a certain level. No explicit figures are available at present.

MR. DONALD BURMISTER.[2]—Are the results independent of moisture content for the same densities?

MR. BERNHARD.—Only wet soil densities could be determined so far. Investigations are planned to determine wet soil density and moisture content with one source-detector combination. The source must emit both—gamma rays for wet soil density determination and neutrons for moisture content determination (Ra-Be). The detector has to be responsive to both types of emissions (lithium-iodide, europium activated scintillation crystal). A cadmium shield around the detector absorbs neutrons. Hence the difference of two measurements, first, with and, second, without this shield, will permit dry soil density determinations.

MR. W. G. HOLTZ.[3]—The Bureau has built a probe, which uses the scattering principle.[4] I should like to ask the authors when the probes are placed in holes in the soils and readings taken, do these measure the soil density between the source and the detector unit. What difference does the air space between the units and the sides of the hole make?

MR. BERNHARD.—The distance between source and detector including air space must be kept constant. Access tubes which are rigidly guided and remain at a fixed distance are lowered into the soil. The air space between soil on the outside and probes on the inside of the access tubes is minimized by using close fits.

MR. HOLTZ.—In deep subsurface drilling work with normal drilling equipment, a rather non-uniform hole is obtained. Will this factor be a disadvantage for deep subsurface work?

MR. BERNHARD.—No difficulties would be encountered to lower source and detector down to 100 ft, once the access tubes are properly placed.

MR. HAROLD G. MASON.[5]—Has any work been done in the more granular soil?

MR. BERNHARD.—No investigations on heavily granulated soils have been made so far.

MR. D. R. LAMB[6] (*by letter*).—In re-

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[1] Professor of Civil Engineering, Georgia Institute of Technology, Atlanta, Ga.

[2] Department of Civil Engineering, Columbia University, New York, N. Y.

[3] Chief, Earth Lab. Branch, U. S. Bureau of Reclamation, Denver Federal Center, Denver, Colo.

[4] Laboratory Report No. SI-6, United States Bureau of Reclamation.

[5] Civil Engineer, U. S. Navy Civil Engineering Research and Evaluation Lab., Resoda, Calif.

[6] Assistant Professor of Civil Engineering, University of Wyoming, Laramie, Wyo.

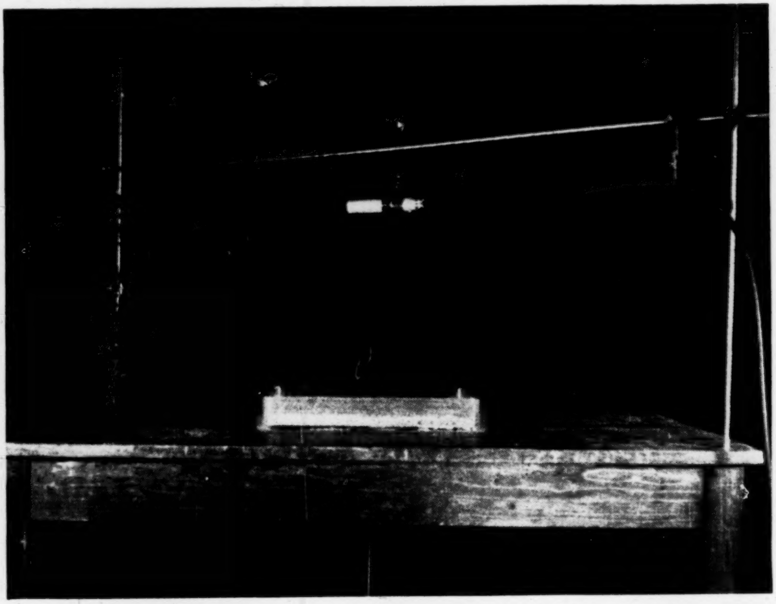

FIG. 17.—The Equipment Used for the Soil Density Determinations.

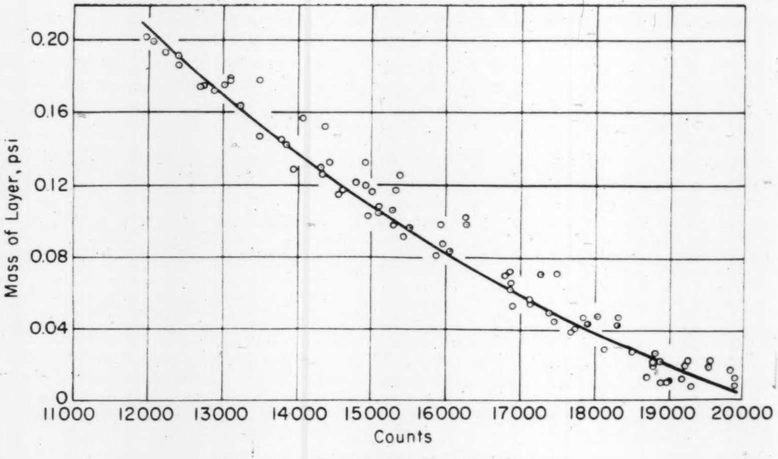

FIG. 18.—Density Calibration Curve.

sponse to the excellent work of the authors in regard to the examination of soil densities using radioactive particles, a résumé of the parallel work carried on at the University of Wyoming under a National Science Foundation Grant will be compared.

It is indeed rewarding to see the excellent results obtained by the use of the scintillation crystal and the 60 millicurie source of cobalt 60. The use of the *GM* tube and up to 12 millicuries of cobalt 60 used by the University of Wyoming limited the effectiveness of sample geometry.

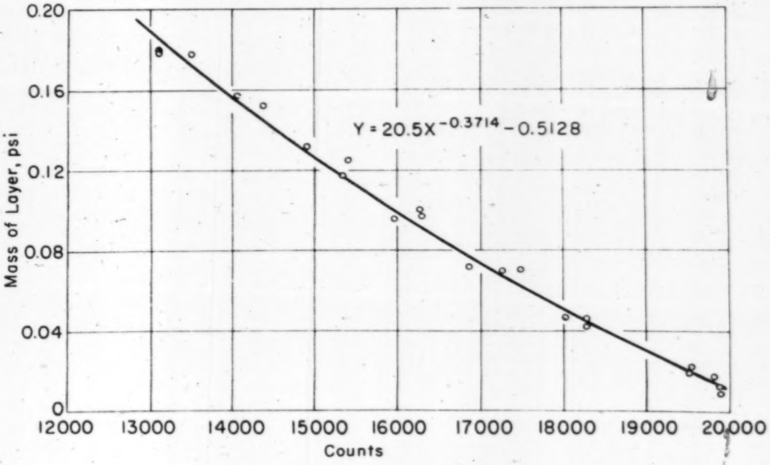

FIG. 19.—Limestone Curve.

In order to overcome this limitation, a special laboratory geometry was set up to offset the instrumentation weakness. The geometry of this procedure is shown in the accompanying Fig. 17 and is given as follows: The *GM* tube was placed $14\frac{1}{4}$ in. above the table top and the cobalt 60 was placed $11\frac{3}{4}$ in. below. The samples were 2 in. thick in a $\frac{1}{4}$-in. lucite container. This placed the cobalt 60 and the *GM* tube 12 in. from the surface of the sample.

The background for this method was made with the empty lucite box on the top of the table centered under the *GM* tube. The counting interval was made long enough to insure the standard deviation of the counts. Soils of different densities were placed in the lucite box and the counts were then recorded.

The results given by the authors and those from the University of Wyoming were somewhat similar. As shown in Figs. 14 and 16 by the authors, there are some scatter of points along the best fit curve. This was also observed in the results given by Belcher *et al.*[7,8,9] and Goldberg *et al.*[10] The same scatter of points was found in our research. Figure 18 shows the general calibration curve using all

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[7] D. J. Belcher, T. R. Cuykendall, and H. S. Sack "The Measurement of Soil Moisture and Density by Neutron and Gamma-Ray Scattering," *Technical Development Report No. 127*, Civil Aeronautics Administration, Technical Development and Evaluation Center, Indianapolis, Indiana, October, 1950.

[8] D. J. Belcher, T. R. Cuykendall, and H. S. Sack, "Nuclear Meters for Measuring Soil Density and Moisture in Thin Surface Layers," *Technical Development Report No. 161*, Civil Aeronautics Administration, Technical Development and Evaluation Center, Indianapolis, Indiana, October, 1950.

[9] D. J. Belcher, R. C. Herner, T. R. Cuykendall, and H. S. Sack, "Use of Radioactive Materials to Measure Soil Moisture and Density," Symposium on the Use of Radioisotopes in Soil Mechanics, Am. Soc. Testing Mats., p. 10 (1952). (Issued as separate publication *ASTM STP No. 134*.)

[10] I. Goldberg, L. J. Tresconv, J. S. Campbell, Jr. and G. J. Whyte, "Measurement of Moisture Content and Density of Soil Masses Using Radioactive Materials," *Proceedings*, Third National Conference on Clays and Clay Technology, Lord Baltimore Press, Baltimore, Md. (1956).

the data. The different materials used were a clay soil from Chugwater formation in Wyoming, Type I portland cement, a crushed limestone from the Casper formation on the western flank of the Sherman Mountains and a sand deposited by the Laramie River in Southeastern Wyoming.

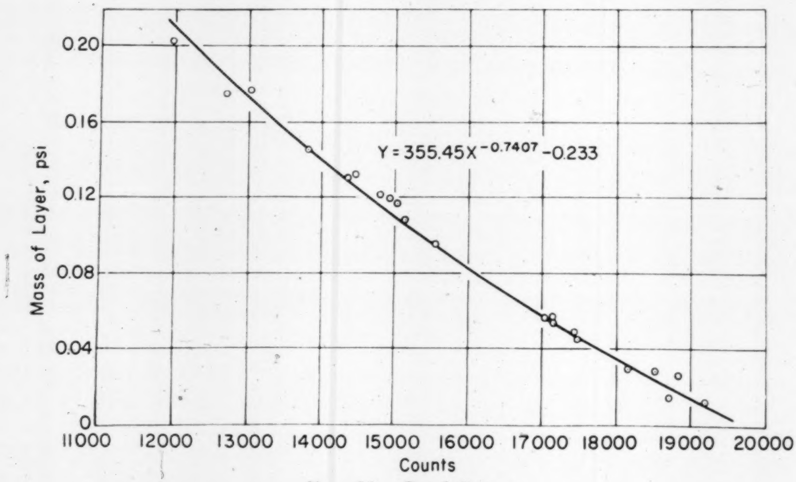

FIG. 20.—Sand Curve.

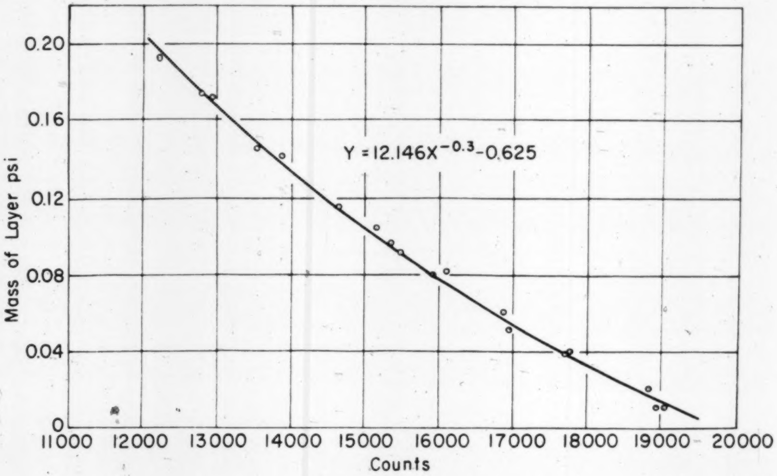

FIG. 21. Cement Curve.

It was first thought that there was too much scatter for good correlation, but upon closer investigation it was noted that if the separate materials were plotted a much better curve was found with good correlation. The separate curves of soil, cement, limestone and sand are shown in Figs. 19, 20, 21, and 22 respectively.

The equations for each curve are given

on each figure. Each curve has a different equation showing that they each filled a rather limited position in the wide band in Fig. 18. The equations were also checked by using the same constants, but the equations were still different and did not check statistically. The curves were checked by statistics as given by Dixon and Massey, "Introduction to Statistical Analysis", pp. 254–256, and were found to be within the 0.025 and 0.975 confidence limits.

Better correlation might be possible if the work were carried on with the thought of using the curves for each of the main soil types instead of one general curve.

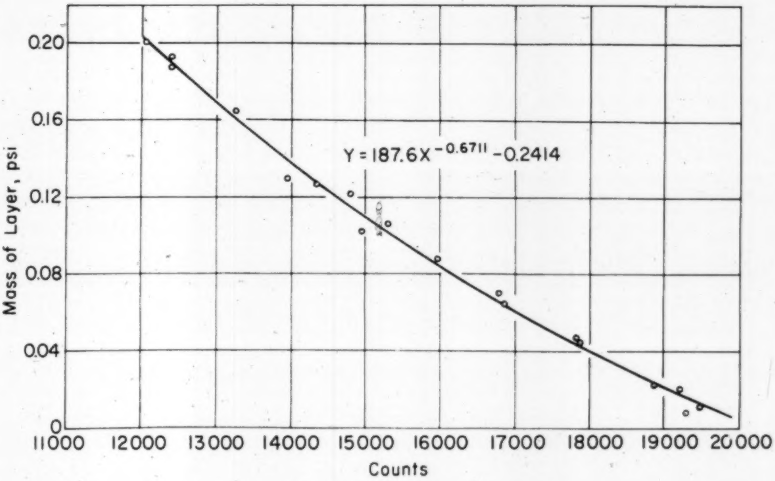

FIG. 22.—Soil Curve.

MESSRS. IRVING GOLDBERG[11] AND LOUIS J. TRESCONY[11] (*by letter*).—The writers are in full agreement with the statements of the authors that present methods employed for the determination of soil density in the field leave much to be desired with respect to reliability and speed. A new approach to this measurement, incorporating the advantages recently gained in understanding the interaction of nuclear radiation with matter, and possessing a number of advantages over methods now used, has been presented in this paper. The authors have conducted a series of carefully planned experiments that have contributed much to the rapidly growing store of knowledge in the determination of soil properties utilizing radioactive materials.

There are two methods by which the measurement of soil density involving gamma radiation has been approached. The scattering technique, investigated by Belcher, *et al.*[12] and Goldberg, *et al.*,[10] involves incorporation of the radioactive source and detector in a single probe, which is then lowered through an access tube into the soil to any desired depth of measurement. The counts recorded represent that radiation which reaches the detector after having been scattered through a roughly spherical volume of soil. The other method, which the authors have used, depends essentially upon the attenuation of gamma radiation through a certain horizontal distance of soil separating the source and the detector, at a fixed depth.

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[11] Graduate Research Engineer and Junior Research Engineer, respectively, Institute of Transportation and Traffic Engineering, University of California, Berkeley, Calif.

[12] D. J. Belcher, T. R. Cuykendall, and H. S. Sack, "The Measurement of Soil Moisture and Density by Neutron and Gamma-Ray Scattering," Technical Development Report No. 127 Civil Aeronautics Administration (1950).

Each approach has certain advantages, depending upon the particular application which is to be made. An important consideration is that the transmission measurement is independent of soil moisture content. This advantage becomes less when simultaneous soil moisture content measurements are made by the neutron scattering technique, to which the single probe method can be applied.[13] The latter method also lends itself to applications where it is desired that the density profile be studied over a considerable depth into the soil, as for example, in settlement studies. The single probe requires only one boring and is considerably smaller in diameter than the transmission apparatus. There is undoubtedly much less disturbance of the soil, minimizing a possible source of error. It is the writers' opinion that the scattering method provides more versatility for field measurements, but that the transmission technique is useful in certain applications where less detailed information is desired.

In the discussion of the results of their laboratory experiments, the authors state on p. 1210, "scattering from the walls of the wooden container as well as from the walls and floor of the laboratory predominates at source-detector distances of more than 4 ft." On p. 1213, the authors state, "In contrast to the laboratory experiments (Fig. 11), however, increasing slopes of the ρ *versus* ln I lines with increasing x become noticeable, indicating a predominant effect of the primary ray." These statements imply that the explanation for this effect is that there is less scattering in the field than in the laboratory.

The writers feel that there may be an alternative explanation for the difference in the trend of the slopes of the calibration curves. On p. 1203, in discussing pulse height control, the statement is made that it was necessary to increase the minimum pulse height level of the scaler so that its mechanical limitations would not be exceeded by the rapid count rates obtained at source-detector distances of less than 3 ft. In Fig. 5 is presented a plot of correction factors used for various pulse height settings. A closer examination of the physical significance of changing the pulse height acceptance level of the scaler proves enlightening. The average energy of the radiation which composes the primary beam is considerably higher than the average energy of the scattered gamma rays. An increase in the discriminator setting will therefore eliminate many of the lower energy pulses, composed primarily of the scattered radiation. Since this setting is higher for the curves obtained in the field (+10 in Fig. 14) than in the laboratory (+5 in Fig. 11), it is possible that the predominant effect of the primary ray in the field tests is due to the fact that large pulses from scattered rays were screened out in this determination. The large differences in the order of magnitude of count rates observed in the comparison of field and laboratory results tends to support this observation.

Since a point source emits radiation into a spherical volume surrounding it, the collimated detector used by the authors will "see" only a very small proportion of the total radiation emitted into the soil by the source. This consideration of the geometry of the system suggests a modification of the method which might be introduced without involving major changes in the apparatus used. The count rate recorded on the scaler is critical. It determines the distance between source and detector, the strength of the source, and the counting time which must be used to minimize statistical errors. An increased count rate would result in more favorable values for these conditions. Utilizing two or more detectors spaced symmetrically around the source in the soil, each detector feeding its pulses into a single scaler, would increase the count rate. An alternative procedure might be to similarly place two or more sources in the soil surrounding a single detector in the center. In the latter case, it would be necessary to modify the collimating system in the detector to receive radiation from each source used. Either of these methods would require the employment of a rigid framework in order to fix accurately the distance between source and detector. Such a framework is suggested even for the apparatus presently used by the authors, since it is noted from Fig. 11 that this distance appears to be quite critical.

In closing, the writers would like to compliment the authors for a valuable contribution toward a more complete understanding of the application of a potentially useful technique.

MR. BERNHARD.—As Messrs. Goldberg and Trescony pointed out, the advantage of the scattering method is that only one hole is required while the transmission method requires two holes. This is true for one measurement only. In most cases more than one measurement (n), is required. When proceeding from the second to the third hole and so forth, only one additional hole ($n + 1$) will become necessary.

The diameter of these holes is independent of the method used and a matter of adequate design of the probes.

The possibility that the distance between source and detector can be adapted to the particular requirements for each investigation is a certain advantage inherent to the transmission method only. This integration over larger distances will avoid misleading results due to insignificant soft or hard inclusions.

The authors would like to express their sincerest appreciation for the valuable contributions of the discussers. It is indeed gratifying that Mr. Lamb's results are similar and that some of the suggestions of Messrs. Goldberg and Trescony have been anticipated and included in the investigation now in progress.

SUMMARY OF PROCEEDINGS OF THE SYMPOSIUM ON HIGH-PURITY WATER CORROSION

The Thirteenth Session of the Fifty-eighth Annual Meeting of the Society held in Atlantic City, N. J., on June 28, 1955, was devoted to the Symposium on High-Purity Water Corrosion sponsored by Committee D-19 on Industrial Water. Of the five papers, one covers methods of preparing and maintaining high-purity water, two deal with the effect of material composition on corrosion in high-purity water at high temperatures, another paper discusses the effect of water composition on corrosion in high-temperature high-purity water, while one paper covers water requirements of various parts of atomic reactor cooling systems.

The following papers were presented:

Methods of Preparing and Maintaining High-Purity Water—F. N. Alquist
The Use of Water in Atomic Reactors—H. W. Huntley and S. Untermyer
Effect of Material Composition in High-Temperature Water Corrosion—A. H. Roebuck
Special Corrosion Study of Carbon and Low Alloy Steels—R. H. Blaser and J. J. Owens
Influence of Water Composition on Corrosion in High-Temperature High-Purity Water—Donald M. Woughton, James M. Seamon and Paul E. Brown

These papers, with discussions, were issued as *ASTM Special Technical Publication No. 179* entitled "Symposium on High-Purity Water Corrosion."

SUMMARY OF PROCEEDINGS OF THE SYMPOSIUM ON INSULATING OILS

This Symposium, the sixth in a series on transformer oils sponsored by Subcommittee IV on Liquid Insulation of Committee D-9 on Electrical Insulating Materials, reports European developments in testing of transformer oils.

Three papers (and discussion) were presented at the 1954 Fall Meeting of the committee held in Cleveland, Ohio on November 17, 1954:

Catalysts for Accelerated Aging Testing of Transformer Oil—Halvard Liander and Gosta Ericson (Sweden)
The Performance Characteristics of Used Insulating Oil—T. Salomon (France)
The Evaluation of Inhibited Transformer Oils—R. Irving and D. W. Bravey (England)

These papers and discussion were issued as *ASTM Special Technical Publication No. 172* entitled "Evaluation of Insulating Oils—European Developments."

SUMMARY OF PROCEEDINGS OF THE SYMPOSIUM ON SPEED OF TESTING

The papers and discussions in the Symposium on Speed of Testing were presented at the Eighteenth Session of the Fifty-eighth Annual Meeting of the American Society for Testing Materials held in Atlantic City, N. J., June 29, 1955. This Symposium was sponsored by Committee E-1 on Methods of Testing. Much has been said and written about the effect of speed of testing on ferrous and non-ferrous materials, but there is an appalling lack of reliable data on effect of testing speed in the testing of most nonmetallic materials. This symposium is only a start toward filling this void.

The papers presented were:

Effect of Speed of Testing on Tensile Strength and Elongation of Paper—Ralph E. Green
Effect of Speed in Plastics Testing—Albert G. H. Dietz and E. J. McGarry
The Influence of Rate of Loading on the Strength of Wood and Wood-Base Materials—L. J. Markwardt and J. A. Liska
Stress-Strain Relationships in Yarns Subjected to Rapid Impact Loading—Herbert F. Schiefer, Jack Smith, Frank L. McCrackin, and Walter K. Stone.
Effect of Speed in Mechanical Testing of Concrete—J. J. Shideler and Douglas McHenry
Effect of Speed of Testing on Tensile Test of Elastomers and Hard Rubber-D. C. Scott and D. S. Villars.
The Effect of Speed of Testing on Glass—H. N. Ritland

These papers with discussion were issued as *ASTM Special Technical Publication No. 185* entitled "Symposium on Speed of Testing."

SUMMARY OF PROCEEDINGS OF CINCINNATI SPRING MEETING

During the 1955 Spring Meeting held in Cincinnati, Ohio, the following Symposium was presented:

SYMPOSIUM ON BASIC EFFECTS OF ENVIRONMENT ON STRENGTH, SCALING, AND EMBRITTLEMENT OF METALS AT ELEVATED TEMPERATURES

Sponsored by the General Research Panel of the ASTM-ASME Joint Committee on Effect of Temperature on Properties of Metals, the Symposium on Basic Effects on Environment on Strength, Scaling, and Embrittlement of Metals at Elevated Temperatures was held in two sessions, morning and afternoon, on February 2, 1955. Mr. Evan A. Davis, Westinghouse Research Laboratories, Westinghouse Electric Corp., East Pittsburgh, Pa., acted as Symposium Chairman. Mr. V. N. Krivobok, International Nickel Co., New York, N. Y., and Mr. W. D. Manly, Oak Ridge National Laboratory, Carbide and Carbon Chemicals Co., Oak Ridge, Tenn., presided.

There are six papers with discussion on oxidation and surface effects comprising this symposium volume, and it is felt that this symposium represents rather accurately the status of the problem of environment at the present time.

The Symposium included the following papers:

Introduction—Evan A. Davis
The Role of Thin Surface Films in the Deformation of Metals Monocrystals—John J. Gilman
Structure of Oxides Formed on High-Temperature Alloys at 1500 F—John F. Radavich
Effect of Strain on the Oxidation of Nickel-Chromium Heater Alloys—Earl A. Gulbransen and Kenneth F. Andrew
An Investigation of Intergranular Oxidation in Type 310 Stainless Steel—R. E. Keith, C. A. Siebert and M. J. Sinnot
The Properties of Oxidation Resistant Scales Formed on Molybdenum-Base Alloys at Elevated Temperatures—M. Gleiser, W. L. Larsen, R. Speiser, and J. W. Spretnak.
Oxidation at Elevated Temperatures—John F. Radavich

These papers, with discussions were issued as *ASTM Special Technical Publication No. 171* entitled "Basic Effects of Environment on the Strength Scaling, and Embrittlement of Metals at High Temperatures."

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LIST OF SPECIAL TECHNICAL PUBLICATIONS

The publications listed below have been printed during the year 1955 and issued as separate publications not included in either Proceedings or ASTM Bulletin. For a list of earlier Special Technical Publications, see the original listings in Proceedings, Volume 48, page 1352, and the supplementary listings in Volume 49, page 1240, Volume 50, page 1490, Volume 51, page 1322, Volume 52, page 1309, Volume 53, page 1197, and Volume 54, page 1388. A complete list of Special Technical Publications covering all publications, up to and including 1950, is included in the 50 Year Index to ASTM Publications.

Special Technical Publication Number	Title
56-I	1954 Supplement to Bibliography and Abstracts on Electrical Contacts
154-A	Supplement to Symposium on Lateral Load Tests on Piles (1955)
169	Significance of Tests of Concrete and Concrete Aggregates (1955)
170	Compilation of Chemical Compositions and Rupture Strengths of Super-Strength Alloys (1955)
171	Symposium on Basic Effects of Environment on Strength, Scaling and Embrittlement of Metals at High Temperatures (1955)
172	Evaluation of Insulating Oils—European Developments (1955)
173	Bibliographical Abstracts on Redeposition of Soil on Cotton Fabrics (1955)
174	Symposium on Metallic Materials for Service at Temperatures Above 1600 F (1955)
175	Symposium on Atmospheric Corrosion of Non-Ferrous Metals (1955)
176	Symposium on Impact Testing (1955)
177	Bibliographical Abstracts on Evaluation of Brightening Agents for Detergent Usage (1955)
178	Panel Discussion on Pyrometric Practices (1955)
179	Symposium on High Purity Water Corrosion (1955)
180	Elevated-Temperature Properties of Carbon Steels (1955)
181	Survey of Copper Base Alloys (DP-7) (1955)
182	Determination of the Shear Stability of Non-Newtonian Liquids (1955)
183	The Mechanical Properties of Wrought Phosphor Bronze Alloys (1955)
184	Glossary of Terms—Rubber and Rubber-Like Materials (1956)
185	Symposium on Speed of Testing (1955)